Performance of Lactating Dairy Cows Fed Varying Amounts of Soyhulls as a Replacement for Corn Grain

I. R. Ipharraguerre,* R. R. Ipharraguerre,† and J. H. Clark*

*Department of Animal Sciences
University of Illinois, Urbana 61801

†Facultad de Agronomía
Universidad de Buenos Aires, Argentina

ABSTRACT

Fifteen multiparous Holstein cows averaging 112 d in milk were used in a replicated 5×5 Latin square to evaluate the incremental substitution of soyhulls for corn in the diet. Diets contained 23% alfalfa silage, 23% corn silage, and 54% concentrate on a dry matter basis. Pelleted soyhulls replaced corn in the concentrate to supply 0, 10, 20, 30, or 40% of the dietary dry matter. Dry matter intake decreased linearly as soyhulls replaced corn in the diet, but the major decrease in dry matter intake occurred when soyhulls provided 30 and 40% of the dietary dry matter. Intakes of both acid and neutral detergent fiber increased linearly as soyhulls increased from 0 to 40% of dietary dry matter. Production of milk tended to decrease when soyhulls supplied 40% of the dietary dry matter. Production of 3.5% fat-corrected milk, milk crude protein percentage and yield, milk urea N, and total solids yield were not affected by treatments. Production of true protein, but not percentage, tended to decrease by about 5% when soyhulls supplied 40% of the dietary dry matter. Increasing the percentage of soyhulls in the dietary dry matter increased linearly milk fat content and yield, and total solids content in milk. These data suggest that soyhulls can successfully supply up to about 30% of the dry matter intake of midlactation cows without depressing animal performance. Furthermore, replacing part of the corn with soyhulls in high grain diets may be viable when milk fat has a high monetary value or when soyhulls can be purchased at a more competitive price than grains on a nutrient content basis.

(Key words: dairy cows, milk production, milk composition, soyhulls)

Abbreviation key: MUN = milk urea nitrogen, SH = soyhulls.

INTRODUCTION

During the commercial processing of soybeans, raw whole soybeans are dried to about 10% moisture, cracked, and separated into meat and hulls (Rhee, 2000). The hulls, which are mainly highly digestible fiber (Titgemeyer, 2000), have little value either for edible human food or for industrial uses. Because of the high digestibility of fiber from soyhulls (SH), the steady increase in the production of soybeans and soybean products since 1970 (USDA, 2001), and the competitive prices at which SH are usually available, many producers have included SH as either a replacement for forage or grain in diets fed to lactating dairy cows.

Even though the partial substitution of SH for grains, particularly corn, in diets of dairy cows has received considerable attention during the last several years, the amount of SH that can be fed to sustain or improve the performance of lactating dairy cows consuming high grain diets remains unclear. In a 98-d continuous trial when high moisture corn was replaced with SH at about 14% of the DM in a diet that contained 48% concentrate, milk yield and milk composition of early lactation cows were not affected (Stone, 1996). Similar findings were obtained in noncontinuous experiments (Bernard and McNeill, 1991; Macgregor and Owen, 1976) in which SH provided from 15 to 28% of the dietary DM. However, in other crossover experiments the replacement of similar proportions of corn with SH (18 to 30% of dietary DM) decreased production of milk and milk protein (Mansfield and Stern, 1994; Pantoja et al., 1994) but increased milk fat percentage, resulting in similar yields of FCM (Mansfield and Stern, 1994; Pantoja et al. 1994; Elliott et al., 1995). Based on data reported by Nakamura and Owen (1989), changes analogous to those of Mansfield and Stern (1994) and Pantoja et al. (1994) in the performance of dairy cows could be anticipated when SH are used to supply more than about 30% of the dietary DM. Recently, it was indicated that the impact of feeding SH to dairy cows is dictated by the energy value of the feedstuff replaced with the hulls (Titgemeyer,

Received December 7, 2002.

Accepted June 15, 2002.

Corresponding author: J. H. Clark; e-mail: jclark@uiuc.edu.

meyer, 2000), the amount and physical form of dietary forages (Grant, 1997), and the potential reduction of negative associative effects following the inclusion of SH in the diet (Firkins, 1997). In view of these observations, it is possible that differences in the amount, type, and/or processing of grains and/or forages fed might have contributed to the contrasting animal responses (Ipharraguerre and Clark, 2002). Furthermore, few studies have concurrently assessed the effects of feeding SH on rumen fermentation, nutrient digestion, nutrient utilization, and performance of lactating dairy cows (Ipharraguerre and Clark, 2002). Thus, the objectives of this experiment were 1) to evaluate the short-term effects on DMI, milk production, and milk composition of the incremental substitution of SH for ground corn in diets of lactating dairy cows and 2) to relate differences in animal performance to alterations in ruminal fermentation, nutrient utilization, and nutrient passage to the small intestine of lactating dairy cows fed diets with the same ingredient composition in a companion experiment (Ipharraguerre et al., 2002).

MATERIALS AND METHODS

Animals, Experimental Design, and Diets

Fifteen multiparous Holstein cows, averaging 642 ± 56 kg and 112 ± 18 DIM at the onset of the experiment, were used in three 5×5 Latin squares conducted concurrently. Each experimental period consisted of 21 d; the first 14 d were used to adapt cows to treatments and the remaining 7 d were used for data collection. Milk production at the beginning of the experiment was the criteria used for assigning cows to the three Latin squares. Milk yield averaged 42, 37, and 32 kg/d for cows in squares 1, 2, and 3, respectively, at the start of the experiment.

Within each square, cows were randomly assigned to treatment sequences in which a treatment never followed the same treatment for all sequences. The control diet contained 46% forage, 54% concentrate, and no SH. For the other dietary treatments pelleted SH replaced corn in the concentrate to supply 10, 20, 30, or 40% of the dietary DM (Table 1). Diets were fed as TMR twice daily at 1000 and 1700 h in amounts to ensure 10% orts. Diets were adjusted weekly to reflect changes in DM content of forages and concentrate mixtures by drying the forages and concentrates overnight at 105°C.

Cows were housed in individual tie stalls equipped with water bowls and were milked twice daily at 0300 and 1500 h.

Sampling, Measurements, and Analyses

Feed offered and refused was recorded daily. During the last 7 d of each period, samples of orts were collected daily and DM content was determined by drying samples from individual cows at 105°C for 24 h. Samples of forages, concentrates, and TMR were collected once a week and divided into two representative subsamples. One subsample of feed was used to determine DM as described for orts and the other subsample was stored frozen at -20°C for later analyses. At the end of each experimental period, feed subsamples from the weekly collections were thawed, combined on an equal weight basis, and sent to the Dairy One, Inc., Forage Testing Laboratory (Ithaca, NY) where they were analyzed for Kjeldahl N (AOAC, 1990), ADF (Van Soest et al., 1991), and NDF with heat-stable α -amylase and sodium sulfite (Van Soest et al., 1991). The NE_L concentration of the TMR was estimated using tabulated values at an intake of three times maintenance (NRC, 2001) for the individual ingredients. The DM concentration of the TMR and orts was used to calculate DMI. Subsequently, intakes of ADF, NDF, CP, and NE_L were estimated with the calculated DMI and the determined (ADF, NDF, and CP) or estimated (NE_L) chemical composition of the TMR.

Milk samples were collected at each milking on d 18 to 21 of each period, preserved with 2-bromo-2-nitropropane-1,3-diol, and stored at 4°C. Samples were sent to Dairy One Cooperative, Inc., Milk Check Laboratory (Ithaca, NY) for analyses of fat, CP, true protein, total solids, and MUN by infrared procedures (Foss 4000; Foss North America, Eden Prairie, MN). Daily milk composition was estimated as an average of the a.m. and p.m. milk samples corrected by the proportion of daily production at that milking.

Body weights were recorded weekly at 0700 h throughout the entire experiment. Body condition scores were determined by two individuals on d 1 of the experiment and on d 21 of each period during the trial using a 5.00 scale in quarter-point increments, where 1 = thin and 5 = fat.

Statistical Analyses

Performance data were analyzed using the GLM procedure and energy balance data were analyzed using the MIXED procedure (SAS, 2000) for a replicated 5×5 Latin square, with square and cow treated as random variables. The following model was used for all dependent variables:

$$Y_{ijkl} = \mu + S_i + C_j (S)_i + P_k + SP_{ik} + T_l + ST_{il} + \epsilon_{ijkl}$$

Table 1. Ingredient and chemical composition of the experimental diets.

Composition	Soyhulls in diet, ¹ %				
	0	10	20	30	40
	(% of DM)				
Ingredient					
Alfalfa silage	23.00	23.00	23.00	23.00	23.00
Corn silage	23.00	23.00	23.00	23.00	23.00
Soyhulls	0.00	10.00	20.00	30.00	40.00
Ground shelled corn	40.32	30.48	20.75	10.88	1.00
Soybean meal, 49% CP	10.50	10.30	10.25	10.25	10.00
Sodium bicarbonate	1.00	1.00	1.00	1.00	1.00
Sodium chloride	0.25	0.25	0.25	0.25	0.25
Dicalcium phosphate	0.50	0.60	0.70	0.80	0.90
Limestone	0.63	0.55	0.22	0.00	0.00
Mineral and vitamin mix ²	0.25	0.25	0.25	0.25	0.25
Magnesium oxide	0.20	0.20	0.18	0.15	0.15
Sodium sulfate	0.35	0.37	0.40	0.42	0.45
Chemical					
DM	55.9	56.6	55.4	55.1	53.8
CP	15.5	15.7	15.8	15.7	16.3
NDF	29.4	34.4	39.9	44.8	49.4
ADF	20.4	24.8	27.3	31.9	34.6
NE _L , Mcal/kg of DM ³	1.66	1.60	1.55	1.50	1.44

¹Soyhulls were substituted for corn in the experimental diets.

²Contained 5.0% Mg, 7.5% K, 10.0% S, 3.0% Zn, 3.0% Mn, 2.0% Fe, 0.5% Cu, 0.025% I, 0.015% Se, 0.004% Co, 2200 IU of vitamin A/g, 600 IU of vitamin D₃/g, and 8 IU of vitamin E/g.

³Calculated using tabulated values at an intake of 3× maintenance (NRC, 2001).

where

- μ = overall mean,
 S_i = effect of square i ($i = 1, 2, 3$),
 $C_j(S)_i$ = effect of cow j nested within square i ($j = 1, 2, 3, 4, 5$),
 P_k = effect of period k ($k = 1, 2, 3, 4, 5$),
 SP_{ik} = interaction of square i and period k ,
 T_l = effect of treatment l ($l = 1, 2, 3, 4, 5$),
 ST_{il} = interaction of square i and treatment l ,
 and
 ε_{ijkl} = residual error.

The degrees of freedom for treatment were partitioned into four single-degree-of-freedom nonorthogonal contrasts: linear, quadratic, 40% SH vs. control, and SH diets vs. control. Linear and quadratic contrasts included the control and all SH diets. Because the square × treatment interaction was not significant ($P > 0.05$) for all variables measured, treatment effects were compared across squares using the contrasts described above.

Differences among treatments were considered to be significant when $P < 0.05$, whereas when $P > 0.05$ but < 0.10 differences were considered to indicate a trend towards a significant effect.

RESULTS AND DISCUSSION

Composition of the Experimental Diets

The CP, NDF, and ADF contents of the corn silage, alfalfa silage, and SH used in the experiment are

shown in Table 2. The increase in the CP percentage of the diets as the concentration of SH in the diet was increased (Table 1) probably resulted from the pelleted SH containing slightly more CP than was expected and the corn contained slightly less CP than was expected. All diets met or exceeded the requirements for CP, RUP, and RDP of cows used in this experiment (NRC, 2001). The dietary concentration of both ADF and NDF increased by almost 70% as the amount of SH in the diet increased from 0 to 40% (Table 1), reflecting the large amount of fiber present in SH (Table 2).

Intakes of DM, ADF, NDF, and CP

The DMI of cows fed the control diet and diets that contained SH did not differ significantly; however, as SH were increased in the diet, DMI decreased linearly ($P < 0.06$; Table 3).

Because ADF and NDF contents of the diets were increased when SH were substituted for corn, cows fed

Table 2. Chemical composition of forages and soyhulls fed in the experimental diets.

Item	Corn silage	Alfalfa silage	Soyhulls
	(% of DM)		
CP	8.2	23.4	10.9
NDF	43.5	39.3	67.1
ADF	29.0	34.6	48.6

Table 3. Least squares means for intakes of DM, ADF, NDF, and CP by lactating dairy cows fed diets containing different amounts of soyhulls.

Item	Soyhulls in diet, ¹ %					SEM	Contrast			
	0	10	20	30	40		SH vs. C ²	Linear	Quadratic	40 SH vs. C ²
Intake	(kg/d)						(P<)			
DM	23.8	24.8	24.4	22.9	22.7	0.63	NS ³	0.06	NS	NS
ADF	4.8	6.2	6.7	7.3	7.9	0.25	0.0001	0.0001	NS	0.0001
NDF	6.9	8.5	9.7	10.2	11.2	0.30	0.0001	0.0001	NS	0.0001
CP	3.7	3.9	3.8	3.6	3.7	0.11	NS	NS	NS	NS

¹Soyhulls were substituted for corn in the experimental diets.

²SH vs. C = Soyhull diets vs. control diet, 40 SH vs. C = 40% soyhull diet vs. control diet.

³NS = Nonsignificant ($P > 0.10$).

diets that contained SH consumed the most ADF and NDF (Table 3). Furthermore, when increasing amounts of SH were substituted for corn in these diets (Table 1) there was a linear increase in intakes of both ADF and NDF in spite of the decreasing DMI (Table 3).

In a number of studies (Bernard and McNeill, 1991; Mansfield and Stern, 1994; Nakamura and Owen, 1989; Sarwar et al., 1992) increasing NDF from 32 to 48% and reducing NSC from 34 to 19% in the diet did not affect DMI. More recently, similar results were obtained when a large proportion of dietary NDF was from mixtures of nonforage sources of fiber (Slater et al., 2000). Enhancement of the rate of digestion and/or the rate of passage of diets that contained SH (Nakamura and Owen, 1989) might have maintained DMI when NDF in the diet increased above 32%, which is a concentration of NDF that has been indicated to depress DMI (Mertens, 1994). In addition, it was proposed that including SH in diets that contained more than 30% starch on a DM basis improved DMI by decreasing the incidence of ruminal upsets (Stone, 1996).

Data from other experiments (Cunningham et al., 1993; Harmison et al., 1997) indicate that DMI decreased when relatively large amounts of NDF from nonforage sources were used to dilute NSC in the diet, which is what we observed (Table 3). Firkins (1997) suggested that when fibrous byproducts are included in the diet of dairy cows with the aim of reducing NSC intake, DMI might be decreased if the resulting concentration of NDF from forages is less than 14 to 16% of the total dietary DM. This decrease in DMI presumably occurs because of reduced effectiveness of those diets to stimulate rumination and salivation or from accumulation of acids and decreased pH of ruminal fluid because of rapid fermentation of the more digestible fiber from nonforage sources (Harmison et al., 1997). The NDF from forage remained above 16% of the total DM in all of our diets, and averaged 19.0% of the total DMI. Therefore, the intake of NDF from

forages decreased from 64.8 to 40.4% and NDF from nonforages (mostly SH) increased from 35.2 to 59.6%. In a companion study (Ipharraguerre et al., 2002), when these diets were fed to dairy cows surgically fitted with rumen and duodenal cannulas the concentration of total VFA in ruminal fluid increased linearly and the pH of ruminal fluid tended to decrease quadratically as SH replaced corn in the diets. Collectively, these data suggest that, under the feeding conditions of this experiment, DMI of cows fed diets that contained 30% or more SH might have been depressed because of a deficient supply of physically effective fiber (Mertens, 1997) and an increased concentration of acids in the rumen.

Crude protein intake averaged 3.7 kg/day per cow for all treatments and was not significantly different among treatments (Table 3). The increase in the percentage of CP in the diet that accompanied the incremental replacement of corn with SH compensated for the decreased DMI when diets that contained increasing amounts of SH were fed to the cows.

Production of Milk and Milk Composition

Milk yield averaged 29.3 kg/d per cow for all treatments (Table 4). Cows fed the diet that contained 40% SH tended ($P < 0.07$) to produce less milk (1.2 kg/d) than cows fed the control diet. In other experiments (Macgregor and Owen, 1976; Bernard and McNeill, 1991; Stone, 1996) when SH were fed to supply from 14 to 28% of the dietary DM to replace corn, milk yield was not affected. However, the complete replacement of corn with SH in high grain diets, which accounted for 30% or more of the dietary DM, either decreased (Nakamura and Owen, 1989) or tended to decrease (Mansfield and Stern, 1994) the production of milk, which is in agreement with our findings when SH replaced corn to supply 40% of the dietary DM. Nakamura and Owen (1989) speculated that feeding large

Table 4. Least squares means for milk production, milk composition, BW change, and BCS of lactating dairy cows fed diets containing different amounts of soyhulls.

Item	Soyhulls in diet, ¹ %						Contrast			
	0	10	20	30	40	SEM	SH vs. C ²	Linear	Quadratic	40 SH vs. C ²
								(P <)		
Milk, kg/d	29.5	29.3	29.9	29.3	28.3	0.48	NS ³	NS	NS	0.07
Fat %	3.60	3.61	3.67	3.93	3.91	0.09	0.09	0.004	NS	0.02
kg/d	0.99	1.00	1.06	1.11	1.08	0.03	NS	0.001	NS	NS
3.5% FCM, ⁴ kg/d	29.0	29.0	30.1	30.6	29.7	0.61	NS	NS	NS	NS
Crude protein %	3.36	3.28	3.33	3.30	3.31	0.19	NS	NS	NS	NS
kg/d	1.05	0.92	0.97	0.94	0.92	0.07	NS	NS	NS	NS
True protein %	3.17	3.15	3.17	3.12	3.13	0.02	NS	NS	NS	NS
kg/d	0.93	0.92	0.94	0.92	0.88	0.03	NS	NS	NS	0.09
Total solids %	12.36	12.41	12.56	12.76	12.67	1.30	0.05	0.006	NS	0.05
kg/d	3.63	3.62	3.73	3.72	3.57	0.11	NS	NS	NS	NS
MUN ⁵ , mg/dl	14.0	14.4	14.4	14.5	14.4	0.39	NS	NS	NS	NS
BW change total kg/21 d	21.3	15.8	10.6	-3.3	-3.0	5.14	0.005	0.0001	NS	0.0009
kg/d	1.02	0.75	0.51	-0.16	-0.14	0.24	0.005	0.0001	NS	0.0009
BCS ⁶	3.07	3.05	3.02	3.00	3.04	0.03	NS	NS	NS	NS

¹Soyhulls were substituted for corn in the experimental diets.²SH vs. C = Soyhull diets vs. control diet, 40 SH vs. C = 40% soyhull diet vs. control diet.³NS = Nonsignificant ($P > 0.10$).⁴3.5% FCM = $0.4324(\text{kilograms of milk}) + 16.216(\text{kilograms of fat})$.⁵Milk urea nitrogen.⁶BCS = Body condition score on a 5.00 scale in quarter point increments where 1 = thin and 5 = fat.

amounts of SH to replace corn reduced the intake of starch, which in turn might limit the supply of glucose for milk synthesis in the mammary gland. In a companion experiment (Ipharraguerre et al., 2002), both the intake and the quantities of NSC digested in the total gastrointestinal tract were markedly depressed when SH replaced corn in the diet, especially for the diet that contained 40% SH. In addition, as SH were increased in the diet the molar proportion of propionate, which is a major gluconeogenic precursor for ruminant animals, tended to decline (Ipharraguerre et al., 2002). Furthermore, feeding the diet that contained 40% SH reduced the passage of NSC to the small intestine by about 50% compared with the control diet (Ipharraguerre et al., 2002). Therefore, these data indicate that replacing 40% of the dietary DM supplied as corn in high grain diets with SH might have decreased milk production by restricting both the amount and source (i.e., NSC) of energy available due to reduced DMI (Table 3) and decreased amounts of NSC digested in the rumen and intestines (Ipharraguerre et al., 2002).

The percentage and yield of fat in milk increased linearly in response to the incremental substitution of SH for corn in the diets (Table 4). This increase in fat counterbalanced the numerically lower milk produc-

tion of cows fed the diet that contained 40% SH, resulting in similar yields of FCM by cows fed all treatments (Table 4). Milk fat and FCM production was unaffected when dairy cows were fed diets in which 30% or less of the dietary DM supplied as corn was replaced with SH (Macgregor and Owen, 1976; Firkins and Eastridge, 1992; Stone, 1996). Mansfield and Stern (1994) suggested that the lack of a response in milk fat percentage from partial replacement of corn with SH might be because there are only small alterations in the molar percentages of total lipogenic VFA (acetate and butyrate). In contrast, when SH replaces more than 30% of the corn in high grain diets, milk fat percentage (Nakamura and Owen, 1989) or yield (Sarwar et al., 1992) normally increases. The increase in milk fat percentage could occur due to a dilution effect caused by a decrease in milk yield; however, an increase in milk fat yield would require an increase in milk yield, milk fat percentage, or both. Nakamura and Owen (1989) concluded, based on the relatively low fat percentage of milk from their control cows (3.13%), that the replacement of large amounts of corn with SH (~48%) only restored milk fat percentage to normal values (3.49%) rather than increasing it. Replacing 30% or more of the dietary DM with SH decreased the yield of FCM because of lower milk produc-

tion in two experiments (Mansfield and Stern, 1994; Nakamura and Owen, 1989) but did not affect milk production in another experiment (Sarwar et al., 1992). However, in the trial of Sarwar et al. (1992) the effects on production of milk and FCM were confounded by the addition of fat to the diet that contained SH.

We observed that the molar proportion of acetate and the acetate to propionate ratio increased linearly when SH replaced up to 40% of the DM supplied as corn in the diet (Ipharraguerre et al., 2002). Likewise, the ratio between lipogenic (acetate plus butyrate) and glucogenic (propionate) VFA increased from 3.67 for the control diet to 3.96 for the diet that contained 40% SH. Increasing the ratio of acetic acid to propionic acid in ruminal fluid might have contributed to an increase milk fat percentage and yield when SH replaced corn in these diets. However, Davis (1979) indicated that milk fat percentage did not decline extensively until the acetic acid to propionic acid ratio declined below 2.2. Another potential reason for the increase in milk fat percentage and yield from cows fed either 30 or 40% SH in the diet might be the loss of body weight experienced by these cows (Table 4); however, differences in BW might be due to changes in gut fill, as discussed later. Furthermore, even though the estimated intake of NE_L decreased linearly as SH increased in the diet, the energy requirements for maintenance and milk production appeared to be lower than the energy supplied by all dietary treatments (Table 5). Therefore, cows in our experiment seemed to be in positive rather than in negative energy balance even

when SH provided more than 30% of the dietary DM (Table 5). A third potential cause for the differences in milk fat content and yield among treatments might be a progressive decrease in *trans*-10, *cis*-12 conjugated linoleic acid formed from fatty acids in corn oil as the amount of corn replaced with SH was increased. The formation of this *trans* fatty acid in the rumen, which appears to be a potent inhibitor of the de novo synthesis of fatty acids in the mammary gland, depends on the alteration of microbial processes in the rumen induced by the diet and the presence of dietary unsaturated fatty acids (Bauman and Griinari, 2001). In our experiment, the amount of *trans*-10, *cis*-12 conjugated linoleic acid formed in the rumen and subsequently supplied to the mammary gland might have decreased as a result of the diminishing intake of unsaturated fatty acids from corn oil when SH replaced corn in the diets. Griinari et al. (1998) reported similar declines of milk fat percentages when lactating dairy cows were fed diets high (36.5% of the dietary DM) in degermed-corn supplemented with corn oil (4% of the diet DM) as a source of unsaturated fatty acids. Furthermore, the shifts in ruminal fermentation (i.e., pH of ruminal fluid and molar proportion of acetate and propionate) reported by Griinari et al. (1998) for the cows supplemented with corn oil paralleled those of the cows fed our control diet (i.e., high corn) in a companion study (Ipharraguerre et al., 2002).

Percentage and yield of CP and the concentration of true protein and MUN in milk were not affected by these dietary treatments (Table 4). However, the yield of true protein tended to decrease by about 5% when

Table 5. Least squares means for estimated energy intake, energy requirements, and energy balance of lactating dairy cows fed diets containing different amounts of soyhulls.

NE_L	Soyhulls in diet, ¹ %					SEM	Contrast			
	0	10	20	30	40		SH vs. C ²	Linear	Quadratic	40 SH vs. C ²
	(Mcal/d)						(P <)			
Intake ⁴	39.31	39.67	37.85	34.42	32.76	1.49	0.04	0.0008	NS ³	0.003
Requirements										
Maintenance ⁵	10.44	10.41	10.30	10.30	10.37	0.18	0.01	0.01	0.01	0.09
Milk ⁶	20.91	20.83	21.17	21.25	20.61	0.74	NS	NS	NS	NS
Total ⁷	31.62	31.20	31.49	31.46	31.26	0.82	NS	NS	NS	NS
Balance ⁸	7.57	8.71	6.57	3.30	1.54	1.28	0.03	0.0003	0.07	0.001

¹Soyhulls were substituted for corn in the experimental diets.

²SH vs. C = Soyhull diets vs. control diet, 40 SH vs. C = 40% soyhull diet vs. control diet.

³NS = Nonsignificant ($P > 0.10$).

⁴Intake = (DMI, kg/d) $\times$ (NE_L /kg DMI) where NE_L was calculated using tabulated values at an intake of 3 $\times$ maintenance (NRC, 2001).

⁵Maintenance = $0.080 \text{ Mcal / kg BW}^{0.75}$ (NRC, 2001).

⁶Milk = $(0.0929 \times \text{Fat \%} + 0.0547 \times \text{CP \%} + 0.192) \times (\text{milk yield, kg/d})$ (NRC, 2001).

⁷Total = Maintenance + milk.

⁸Balance = Intake – total requirements.

SH supplied 40% of the dietary DM compared with the control diet. These findings agree with previous research data indicating that the percentage and/or yield of milk protein was either maintained (Bernard and McNeill, 1991; Elliott et al., 1995; Stone, 1996) or reduced (Nakamura and Owen, 1989; Mansfield and Stern, 1994; Pantoja et al., 1994), but never enhanced, when SH replaced grains in diets for lactating dairy cows. According to other reports (Ipharraguerre et al., 2002; Mansfield and Stern, 1994; Nakamura and Owen, 1989) replacing 40% of the dietary DM supplied as corn in the diet with SH might have resulted in a trend towards a lower yield of milk protein because of a limited supply of energy, Met, or both.

The percentage, but not the yield, of total solids in milk was increased by increasing the percentage of SH in the diets (Table 4). Similar results were obtained when 48% of the dietary DM was supplied as SH to replace corn (Nakamura and Owen, 1989).

Although BCS were unaffected by treatments, total and daily BW change decreased linearly as the percentage of SH increased from 0 to 40% of the dietary DM (Table 4). Because in this experiment cows appeared to be in positive energy balance (Table 5), differences in BW might be due to changes in gut fill rather than losses of body tissues. In this case, reduced gut fill might have resulted from the lower DMI for cows fed either 30 or 40% SH diets and from the speculated more rapid rate of passage from the rumen when these diets were fed. Firkins and Eastridge (1992) reported that replacing corn (~21%) and soybean meal (~10%) with SH (~20%), roasted soybeans (~11%), and inert fat (~0.43%) tended to decrease the BW of cows that were fed the diets that contained SH in a 16-wk trial. However, BW of primiparous and multiparous lactating cows was not changed when SH replaced 14% of the dietary DM supplied as high moisture corn in a 98-d trial (Stone, 1996). Unfortunately, there is a paucity of data from continuous experiments in which SH replaced relatively large amounts of corn in diets for lactating dairy cows.

CONCLUSIONS

Substitution of SH for corn to supply in excess of 30% of dietary DM in high ($\geq 50\%$) concentrate diets for midlactation cows may decrease DMI and milk production. In contrast, milk fat percentage and yield may be increased when SH are substituted for corn in the diet. These data suggest that SH can successfully supply up to about 30% of the DMI of midlactation cows without depressing animal performance in the short term. Moreover, these data indicate that continuous experiments starting during early lactation are needed

to assess the long term effects of replacing large amounts of the DM supplied as corn with SH. The monetary value of milk fat and the price of SH compared with corn or other grains should be considered when determining the viability of substituting SH for grains.

REFERENCES

- Association of Official Analytical Chemists. 1990. Official Methods of Analysis. Vol. I. 15th ed. AOAC, Arlington, VA.
- Bauman, D. E., and J. M. Griinari. 2001. Regulation and nutritional manipulation of milk fat: low-fat milk syndrome. *Livest. Prod. Sci.* 70:15–29.
- Bernard, J. K., and W. W. McNeill. 1991. Effect of high fiber energy supplements on nutrient digestibility and milk production of lactating dairy cows. *J. Dairy Sci.* 74:991–995.
- Cunningham, K. D., M. J. Cecava, and T. R. Johnson. 1993. Nutrient digestion, nitrogen, and amino acid flows in lactating cows fed soybean hulls in place of forage or concentrate. *J. Dairy Sci.* 76:3523–3535.
- Davis, C. L. 1979. The use of buffers in the rations of lactating dairy cows. Pages 51–64 in *Regulation of Acid-Base Balance*. L. C. Hallman, Jr., and R. W. Rice, ed. Church & Dwight Company, Inc., Piscataway, NJ.
- Elliott, J. P., J. K. Drackley, G. C. Fahey Jr., and R. D. Shanks. 1995. Utilization of supplemental fat by dairy cows fed diets varying in content of nonstructural carbohydrates. *J. Dairy Sci.* 78:1512–1525.
- Firkins, J. L. 1997. Effects of feeding nonforage fiber sources on site of fiber digestion. *J. Dairy Sci.* 80:1426–1437.
- Firkins, J. L., and M. L. Eastridge. 1992. Replacement of forage or concentrate with combinations of soyhulls, sodium bicarbonate, or fat for lactating dairy cows. *J. Dairy Sci.* 75:2752–2760.
- Grant, R. J. 1997. Interactions among forages and nonforage fiber sources. *J. Dairy Sci.* 80:1438–1446.
- Griinari, J. M., D. A. Dwyer, M. A. McGuire, D. E. Bauman, D. L. Palmquist, and K. V. V. Nurmela. 1998. Trans-octadecenoic acids and milk fat depression in lactating dairy cows. *J. Dairy Sci.* 81:1251–1261.
- Harmison, B., M. L. Eastridge, and J. L. Firkins. 1997. Effect of percentage of dietary forage neutral detergent fiber and source of starch on performance of lactating Jersey cows. *J. Dairy Sci.* 80:905–911.
- Ipharraguerre, I. R., and J. H. Clark. 2002. Soyhulls as an alternative feed for lactating dairy cows: A review. *J. Dairy Sci.* (Accepted)
- Ipharraguerre, I. R., Z. Shabi, J. H. Clark, and D. E. Freeman. 2002. Ruminant fermentation and nutrient digestion by dairy cows fed varying amounts of soyhulls as a replacement for corn grain. *J. Dairy Sci.* 85:2902–2916.
- Macgregor, C. A., and F. G. Owen. 1976. Effect of increasing ration fiber with soybean mill run on digestibility and lactation performance. *J. Dairy Sci.* 59:682–689.
- Mansfield, H. R., and M. D. Stern. 1994. Effects of soybean hulls and lignosulfonate-treated soybean meal on ruminal fermentation in lactating dairy cows. *J. Dairy Sci.* 77:1070–1083.
- Mertens, D. R. 1994. Regulation of feed intake. Pages 450–493 in *Forage Quality, Evaluation, and Utilization*. G. C. Fahey, ed. American Society of Agronomy, Inc., Madison, WI.
- Mertens, D. R. 1997. Creating a system for meeting the fiber requirements of dairy cows. *J. Dairy Sci.* 80:1463–1481.
- Nakamura, T., and F. G. Owen. 1989. High amounts of soyhulls for pelleted concentrate diets. *J. Dairy Sci.* 72:988–994.
- National Research Council. 2001. *Nutrient Requirements of Dairy Cattle*. 7th rev. ed. Natl. Acad. Sci., Washington, DC.
- Pantoja, J., J. L. Firkins, M. L. Eastridge, and B. L. Hull. 1994. Effects of fat saturation and source of fiber on site of nutrient digestion and milk production by lactating dairy cows. *J. Dairy Sci.* 77:2341–2356.

- Rhee, K. C. 2000. Processing technology to improve soy utilization. Pages 46–55 in *Soy in Animal Nutrition*. J.K. Drackley, ed. Fed. Anim. Sci. Soc., Savoy, IL.
- Sarwar, M., J. L. Firkins, and M. L. Eastridge. 1992. Effects of varying forage or concentrate carbohydrates on nutrient digestibilities and milk production by dairy cows. *J. Dairy Sci.* 75:1533–1542.
- SAS. 2000. SAS System for Windows. Release 8.1 (TS1 MO). SAS Institute, Inc. Cary, NC.
- Slater, A. L., M. L. Eastridge, J. L. Firkins, and L. J. Bidinger. 2000. Effects of starch and level of forage neutral detergent fiber on performance by dairy cows. *J. Dairy Sci.* 83:313–321.
- Stone, W. C. 1996. Applied topics in dairy cattle nutrition. 1. Soy-hulls as either forage or concentrate replacement. Ph.D. Thesis. Cornell Univ., Ithaca, NY.
- Titgemeyer, E. C. 2000. Soy byproducts as energy sources for beef and dairy cattle. Pages 238–256 in *Soy in Animal Nutrition*. J.K. Drackley, ed. Fed. Anim. Sci. Soc., Savoy, IL.
- USDA. 2001. Subject: statistical highlights 2000/2001. http://www.usda.gov/nass/pubs/stathigh/2001/tables/crops_1.htm. Accessed Sep. 22, 2001.
- Van Soest, P. J., J. B. Robertson, and B. A. Lewis. 1991. Methods for dietary fiber, neutral detergent fiber, and nonstarch polysaccharides in relation to animal nutrition. *J. Dairy Sci.* 74:3583–3597.