Influence of Dietary Nonfiber Carbohydrate Concentration and Supplementation of Sucrose on Lactation Performance of Cows Fed Fescue Silage

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ABSTRACT

There is interest in knowing if the source of nonfibrous carbohydrates (NFC) influences milk production and composition. Our objective was to determine the effects of source (starch or sugar) and level of NFC in the diet on these parameters. A 4 × 4 Latin square replicated five times using early-lactation (56 ± 9 DIM) Holstein cows was used; cows were offered one of two levels of NFC and either no added sucrose or sucrose substituting for 10% of the corn. Diets were balanced to meet National Research Council requirements for total protein, energy, and minerals. Tall fescue silage was included at one of two levels (0.95 or 1.25% of BW as forage NDF), resulting in diets with 40 and 30% NFC. The remaining ingredients consisted of high-moisture corn, soybean meal, SoyPlus, minerals, and vitamins. Megalac (0.45 kg) was used in the low NFC diets. High NFC diets were lower ($P < 0.01$) in neutral detergent fiber (NDF; 31.5%) and crude protein (CP; 19.6%) than the low NFC diet (35.8% NDF and 21.0% CP). Sucrose containing diets were somewhat lower ($P < 0.01$) in NDF (33.1%) than the no sucrose added diets (34.3%), but diets did not differ in CP%. Cows offered the high NFC level produced more milk (39.6 kg/d; $P < 0.05$) than those offered the low level (38.3 kg/d), primarily due to higher dry matter intake ($P < 0.05$). Cows consuming the high NFC diet also had lower ($P < 0.05$) milk fat (3.25%) and milk urea nitrogen (MUN; 13.7 mg/dl), and higher ($P < 0.05$) milk protein (2.58%) and milk lactose (4.81%) concentrations than cows offered the low NFC level (3.46% milk fat, 17.5 mg/dl MUN, 2.51% milk protein, and 4.74% milk lactose). Fat yield was higher ($P < 0.05$) for cows fed low NFC diets than cows fed high NFC diets, whereas protein and fat yield were lower ($P < 0.05$) for cows fed low NFC diets than those fed high NFC

diets. The NFC source did not influence dry matter intake or milk production or milk component yield ($P > 0.05$). Milk lactose (4.79%) and MUN (16.0 mg/dl) concentrations were higher ($P < 0.05$) for cows offered sucrose as a portion of the NFC compared with those not offered sucrose (4.76% milk lactose and 15.2 mg/dl MUN). Results suggest that cows fed sucrose may utilize diet nitrogen less efficiently than those not fed sucrose, when sucrose is replacing a portion of the high-moisture corn in the diet.

(**Key words:** grass, nonfiber carbohydrate, sucrose)

Abbreviation key: NFC = nonfibrous carbohydrate.

INTRODUCTION

Milk production per cow continues to be a major factor in determining dairy farm sustainability/profitability. The inclusion of nonfibrous carbohydrates (NFC) in the range of 35 to 42% of dietary DM is seen as a popular way to increase energy density and thus milk production (Lykos et al., 1997). Balance of carbohydrates in the diet impacts milk production because it affects amount and ratios of ruminal VFA produced, which in turn alters metabolism and partitioning of nutrients (Mertens, 1992). Carbohydrates indirectly affect milk production by altering microbial protein production and amino acid supply (Mertens, 1992). Vagnoni and Broderick (1997) suggested that enhancing the availability of ruminal fermentable energy could increase microbial capture of RDP in alfalfa silage, which has extensive conversion of protein to NPN during the fermentation process. Chamberlain et al. (1985, 1993) also reported that addition of readily fermentable carbohydrates (sugars) increased N utilization efficiency of sheep and steers. Total sugar content of many diets is low, only 1.5 to 3.0% of diet DM (Hoover and Webster, 2001). Hoover and Webster (2001) noted reductions in ruminal ammonia in nearly all studies in which sugars were added to the diets, suggesting more efficient utilization of rapidly avail-

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Table 1. Chemical and fermentation analysis of fescue silage.

Component ¹	Period 1	Period 2	Period 3	Period 4
DM	31.5	23.3	31.1	26.7
CP	17.1	15.1	14.6	15.6
Soluble protein, % of CP	62	69	61	68
ADIP ² , % of DM	0.6	0.5	0.8	0.6
NDIP ³ , % of DM	1.7	1.2	2.2	1.7
Acid detergent fiber	35.1	39.9	37.3	36.9
Neutral detergent fiber	55.5	63.2	62.5	58.6
Lignin	5.2	5.2	5.5	3.8
NFC ⁴	15.6	9.6	11.9	13.7
Fermentation				
Lactic acid	8.85	4.49	7.58	6.98
Acetic acid	0.96	3.73	1.52	2.86
Propionic acid	0.14	0.64	0.0	0.16
Butyric acid	0.0	0.0	0.0	0.0
Total acids	9.95	8.86	9.14	10.04
pH	4.3	4.6	4.3	4.3
Ammonia-N, % of Total N	8.5	11.4	11.0	9.2

¹Reported as % of DM. Samples were analyzed by Dairy One (DHI Forage Testing Lab, Ithaca, NY).

²ADIP = Acid detergent insoluble fiber.

³NDIP = Neutral detergent insoluble fiber.

⁴Nonfibrous carbohydrate. $NFC = 100 - (\%NDF + (\%CP - \%NDIP) + \%Fat + \%Ash)$ (NRC, 2001).

able nitrogen. Forages differ in rate of passage and buffering capacity, and this will influence response to level and source of NFC in the diet (Moore et al., 1990). Although there have been few studies in the United States with cows fed predominantly grass-based TMR, there are a number of European studies regarding how dairy cows on predominantly grass-based TMR will respond to changes in levels and sources of concentrates. Many of these studies either dealt with perennial ryegrass (*Lolium perenne* L.) as the forage source or included less concentrate in diets than would be required for high-producing dairy cows in the United States (Thomas, 1988; Keady et al., 1998; Fitzgerald and Murphy, 1999). With this in mind, our objectives were to determine the influence of altering the level of NFC and replacing some of the high-moisture corn grain with sucrose on milk production and composition of high producing dairy cows (>35 kg/d) fed a fescue-based TMR.

MATERIALS AND METHODS

Twenty lactating (563 ± 61.2 kg BW, 49.2 ± 5.91 kg/d milk yield, 1.8 ± 0.83 parity, 56 ± 9 DIM) Holstein cows were assigned to a 4 × 4 Latin square design replicated five times. Dietary treatments consisted of two levels of NFC and two levels of sucrose in the diet. The concentration of NFC in the diets was achieved by including a first-cutting vegetative fescue (*Festuca arundinacea* Schreb.) silage (Table 1). The NFC level was achieved by changing the fescue percentage of diet DM. Sucrose was not included or was included to

replace 10% of the high moisture corn in each TMR (Table 2). The TMR were balanced for minimum requirements for energy and minerals (NRC, 2001). Total CP in TMR was higher than minimum requirements to ensure that CP would not be a limiting factor for a sucrose response. In addition to the fescue silage, high moisture corn grain, soybean meal, SoyPLUS, macrominerals, microminerals, and vitamins were included in the diet (Table 2). Megalac was included in the low NFC diet so that energy in the two diets would be similar.

Fescue silage and ration components were analyzed by Dairy One (DHI Forage Testing Lab, Ithaca, NY) for DM, CP, ADF, NDF, ADF-CP, NDI-CP, soluble protein, fat, lignin, and ash. Dry matter was determined by drying at 135°C for 2 h (AOAC 930.15, 1990). Nitrogen was determined by combustion (Leco Instruments, Inc., St. Joseph, MI) (AOAC 976.06, 1990) and multiplied by 6.25 to obtain CP. Neutral detergent fiber, ADF, and sulfuric acid lignin were analyzed according to Van Soest et al. (1991) using the ANKOM system for NDF and ADF. Sulfite and heat stable alpha-amylase were used for NDF analysis of all samples. Samples were not corrected to an ash-free basis. Soluble protein was determined using a sodium-borate sodium phosphate buffer procedure (Licetra et al., 1996). Fat (ether extract) was determined using a Tecator Soxtec System. Ash was determined by dry combustion (AOAC 942.05, 1990). The NFC was calculated as $NFC = 100 - (\%NDF + (\%CP - \%NDIP) + \%Fat + \%Ash)$ (NRC, 2001). The NFC of TMR was determined by analysis of individual components. Fermentation

Table 2. Ingredients of diets (% of DM).

Item	HNFCN ¹	HNFCS	LNFCN	LNFCN
Ingredients				
Fescue silage	46.8	46.8	57.7	57.7
Corn grain, high-moisture	35.7	32.1	19.2	17.3
Soybean meal	4.5	4.5	6.4	6.4
SoyPLUS ²	10.0	10.0	11.7	11.7
Sucrose ³	...	3.6	...	1.9
Megalac	...	...	2.1	2.1
Mineral-Vitamin mix ⁴	3.0	3.0	2.9	2.9

¹HNFCN = high NFC (nonfibrous carbohydrate), no sucrose; HNFCS = high NFC, sucrose; LNFCN = low NFC, no sucrose; LNFCN = low NFC, sucrose.

²West Central Soy, Ralston, IA.

³From Round House Milling Company, Cortland, NY.

⁴Mineral-vitamin mix from Round House Milling Company, Cortland, NY. Mix was 18.4% sodium chloride, 18.45% limestone, 5.9% dicalcium phosphate, 44.1% calcium sulfate, 8.8% Round House Vit-Trace, 3.6% Round House Trace Base, and 0.75% Round House Mini-Fort. Round House Vit-Trace guaranteed analysis—Ca (min) 3.54%, Ca (max) 4.54%, P (min) 0.2%, Mg (min) 24.81%, K (min) 6.57%, Sulfur (min) 7.93%, Fe (min) 0.303%, Zn (min) 2.4232%, Mn (min) 2.22%, Cu (min) 0.404%, I (min) 0.0519%, Co (min) 0.0138%, Se (min) 0.02440%, vitamin A (IU) 1,329,620/kg, vitamin D (IU) 323,796/kg, vitamin E (IU) 3891/kg. Round House Trace Base guaranteed analysis—Su (min) 3.5%, Fe (min) 8.00%, Zn (min) 18%, Mn (min) 15%, Cu (min) 2%, I (min) 0.2%, Co (min) 0.2%. Round House Mini Fort guaranteed analysis—Ca (max) 14%, Ca (min) 13%, Mg (min) 10%, K (min) 4.5%, Su (min) 5.7%, Fe (min) 0.23%, Zn (min) 0.26%, Mn (min) 0.22%, Cu (min) 0.03%, I (min) 0.02%, Co (min) 0.003%.

analysis of grass haylage was performed by Dairy One (DHI Forage Testing Lab, Ithaca, NY). Forage samples, blended for 2 min in deionized water and filtered, were mixed 1:1 with 0.06 *M* oxalic acid. Samples were analyzed for acetic, propionic, butyric, and iso-butyric acids using gas chromatography (Anonymous, 1990). Lactic acid was determined using a YSI 2700 SELECT Biochemistry Analyzer equipped with an L-lactate membrane. Ammonia N was also determined (AOAC 941.04, 1990).

Each period consisted of 21 d, a 14-d adjustment period followed by a 7-d collection (feed offered and refused). Cows were randomly assigned to treatments. Cows were offered their assigned TMR once daily between 1000 and 1100 h to allow ad libitum intake with a 10% refusal. Intakes and refusals were recorded daily for each cow. During d 15 to 21, samples of feed offered and refused were collected and frozen for subsequent analysis. Cows were maintained in tie stalls during the trial. Diet and refusal composites for each cow and period were analyzed for crude protein (CP; $N \times 6.25$), NDF, ADF, and sulfuric acid lignin. Sulfite and heat stable alpha-amylase were used for NDF analysis of all samples. Samples were not corrected to an ash-free basis. Nitrogen was determined by combustion (Leco Instruments, Inc., St. Joseph, MI). Neutral detergent fiber, ADF, and sulfuric acid lignin were analyzed according to Van Soest et al. (1991) using the ANKOM system for NDF and ADF.

Cows were milked three times daily (0800, 1600, and 2400 h) in a milking parlor. Milk production was monitored daily. During the collection period, milk was

sampled at each milking and composited daily. Samples were preserved with 2-bromo-2-nitropropane-1, 3 diol. Samples were analyzed for fat, milk true protein, MUN, lactose, and SCC at the New York DHI milk testing laboratory (Ithaca, NY; infrared analysis: Foss 605B Milko-Scan; Floss Electric, Hillelrod, Denmark).

Two cows from each treatment of the production trial were used to determine apparent total tract nutrient digestibility and nitrogen balance (eight cows total). For nitrogen balance calculations, individual intakes of nitrogen were used. These cows were moved into metabolism stalls 2 d before the data collection period. Milking necessitated the cows being released from the tie stalls to go to the milking parlor. Some fecal loss occurred during this time. There was less urine loss, as all catheters were capped during milking. It is assumed that fecal losses were roughly equivalent among treatments. At the conclusion of the collection week, cows were returned to tie stalls. Time out of stalls averaged 20 to 30 min per milking.

One day before collection, indwelling Bardex Foley urine catheters (75 cm³, Bard Urological Division, Covington, GA) were placed in cows for total urine collection. Total urine volume was measured every 24 h for 5 d. Catheters were attached via plastic tubing to sealed 22.7-L bags (Polygal, Janesville, WI), which were changed three times daily (after each milking). During milking, catheters were detached from bags and plugged. Urine from the three bags for a 24-h period was combined, weighed, and acidified with 250 ml of 18 *N* H₂SO₄. Bags were not acidified because of safety concerns for the cows. Bags were sealed at all

times before acidification, and average minimum/maximum barn temperatures were $-2.3/3.3^{\circ}\text{C}$, $-0.8/7.8^{\circ}\text{C}$, $6.7/15.9^{\circ}\text{C}$, and $11.4/27.3^{\circ}\text{C}$ for periods 1 to 4, respectively. Because of this, we did not correct for urinary N loss as ammonia. We recognize that this may have resulted in a slight underestimation of urinary N loss. Spanghero and Kowalski (1997) estimated that urinary N loss of 5% would occur if no preservative was used, although they admit the correction is somewhat arbitrary. They based this on the reported loss of 15% of urinary N as ammonia in 2 to 3 wk when urine was added to the soil (Lockyear and Whitehead, 1990). Urine was subsampled (1%), with daily collections being composited for the week and frozen.

Feces were collected in Teflon trays located beneath the cows. Daily feces were mixed, weighed, and subsampled (3%) each morning of the collection period. Daily samples were composited for the collection period for each cow and frozen. For DM analysis, a subsample was dried at 100°C . The remainder of each sample was dried at 55°C and ground to pass a 1-mm screen in a cyclone mill (UDY Corporation, Fort Collins, CO) for subsequent analyses.

Feces were analyzed for variables as outlined above for feeds. This included sodium sulfite and alpha-amylase being used for NDF analyses. Fecal N was corrected for loss of N during drying according to the procedures of Juko et al. (1961). Spanghero and Kowalski (1997) indicated that the drying process resulted in lower N/kg DM (2.26 kg N/kg DM) as opposed to wet samples (2.64 kg of N/kg of DM). They indicated that the equation of Juko et al. (1961) gave the same deviation as they found between wet and dry fecal samples in their review of 35 N balance trials with 125 different diets, suggesting that the equation could be used for correction of losses during drying. Urine was analyzed for CP. The CP was estimated by Kjeldahl N $\times 6.25$.

In vitro fiber digestibility and digestion kinetics of TMR for each treatment $\times$ period were determined according to Cherney et al. (1997), using the rumen buffer described by Marten and Barnes (1980) and using the Daisy II^{200/220} in vitro incubator (ANKOM Technology, Fairport, NY) and the ANKOM^{200/220} fiber analyzer (ANKOM Technology, Fairport, NY). The buffer contained urea. Ruminal fluid inoculum was obtained from a nonlactating, rumen-fistulated Holstein cow offered a medium quality orchardgrass (*Dactylis glomerata* L.) hay diet ad libitum. Digestibility samples (0.25 g) were incubated for 48 h at 39°C , and undigested residues were treated with neutral detergent solution. Incubation times for digestion kinetics were 0, 6, 12, 18, 24, 36, 48, and 72 h. Duplicate sam-

ples were included for each time point, and separate incubation bottles were used for each time point. Estimates for kinetic parameters of digestion were determined using the Marquardt option of procedure of NLIN (SAS, 1998). The model for kinetics of digestion was a simple first-order kinetic equation with a discrete lag time (Mertens and Loften, 1980).

Data were analyzed using repeated measures analysis models in the PROC MIXED procedure in SAS, version 7.0 software (SAS, 1998) according to Templeman and Douglass (1999). The covariance structure was assumed to be first order autoregressive, and degrees of freedom were calculated using the Satterthwaite method. Period is repeated with the subject being cow. There were 7 d per period for each cow. Statistical design was a 4×4 Latin square with five cows per treatment. Treatment consisted of two levels of NFC and two levels of sucrose. Significance was $P < 0.05$ unless otherwise stated. The following model was used:

$$Y_{ijk} = \mu + \pi_i + \rho_j + \delta_k + \alpha_l + \delta_{k*}\alpha_l + \varepsilon_{ijkl}$$

where:

y_{ijk} = the dependent variable,

μ = overall mean,

π_i = cow ($i = 1, 2, 3, 4, 5$ for production variables) and ($i = 1, 2$ for N balance and apparent digestibilities),

ρ_j = period ($j = 1, 2, 3, 4$),

δ_k = NFC source ($k = 1, 2$),

α_l = NFC level ($l = 1, 2$),

$\delta_{k*}\alpha_l$ = interaction term for source and level,

ε_{ijkl} = residual error.

The study had Cornell University Institutional Animal Care and Use Committee approval. All animals were used in compliance with federal, state, and local laws and regulations involving animal care and use, and the study was conducted in such a manner as to avoid unnecessary animal discomfort.

RESULTS AND DISCUSSION

Crude protein content was similar within the high NFC diets ($19.8 \pm 0.92\%$) and low NFC diets (20.6 ± 0.90), but tended to be higher in the low NFC diets (Table 3). Diets were formulated to be higher than NRC (2001) recommendations for CP to ensure that responses due to sucrose supplementation would not be limited by ruminal NH_3 . Sannes et al. (2002) suggested that beneficial responses to sugar might require

Table 3. Chemical analysis and in vitro digestion kinetics¹ of diet (% of DM).

	Diet ¹				SE	Contrast ²		
	HNFCN ³	HNFCS	LNFCN	LNFCS		Sucrose	Forage	S × F
CP	19.9	19.6	20.6	20.6	0.44	0.70	0.08	0.66
Soluble CP, % of CP	32.5	33.3	35.8	32.3	0.94	0.18	0.26	0.05
Acid detergent fiber	20.9	20.5	24.2	23.2	0.64	0.17	0.01	0.58
Neutral detergent fiber	35.4	34.9	40.4	38.9	0.37	0.03	0.01	0.21
Lignin	3.55	3.45	3.65	3.70	0.024	0.33	0.01	0.01
NFC ⁴	35.7	36.5	30.0	31.4	0.62	0.11	0.01	0.64
Rate of NDF digestion, h ⁻¹	0.071	0.114	0.096	0.061	0.0178	0.82	0.45	0.06
D ₀ , % of DM	23.8	22.2	25.6	27.8	1.65	0.80	0.01	0.13
Indigestible residue, % of DM	12.7	15.2	15.2	11.54	1.43	0.70	0.70	0.06
Extent of NDF digestion, %	77.6	73.5	75.7	77.5	2.71	0.69	0.70	0.30

¹Digestion kinetics determined according to Mertens and Loften (1980). D₀ = potentially digestible fiber expressed as a percentage of DM in the original sample; Indigestible residue = indigestible NDF expressed as a percentage of DM in the original sample.

²Contrast compares effect of carbohydrate source (sucrose or no sucrose) and forage level (47 or 58% of diet) and the interaction between carbohydrate source and forage level (SXF).

³HNFCN = high NFC (nonfibrous carbohydrate), no sucrose; HNFCS = high NFC, sucrose; LNFCN = low NFC, no sucrose; LNFCS = low NFC, sucrose.

⁴NFC = 100 - (%NDF + (%CP - %NDIP) + %Fat + %Ash (NRC, 2001).

increased dietary RDP levels to avoid a rumen NH₃ limitation.

The NDF and ADF were lower in high NFC diets, as would be expected (Table 3). The NDF was also lower in the sucrose diets, and the ADF tended to be lower in the sucrose diets. This was due to the sucrose replacing a portion of the high-moisture corn, which contained 13.8% NDF. The NFC was lower in the low NFC diets. The NFC did not vary with sucrose level in the diet. There was an interaction for lignin between source and level. At high levels of NFC, lignin levels were not different between sugar sources, although there was a trend for the corn diet to be slightly higher than the sucrose diet ($P = 0.068$). At low level of NFC, lignin content of the corn diet was not different from the sucrose diet ($P = 0.498$).

Daily milk production was higher in high NFC diets than low NFC diets (Table 4). Dry matter intakes for cow fed sucrose or corn diets were not different. High NFC diets resulted in higher cow DM intake than low NFC diets. Intake of forage NDF was higher for the low NFC diets. More concentrate in the diet leads to higher milk production (Weiss and Shockey, 1991). In vitro rate of NDF digestion (0.086 ± 0.037) was not influenced by dietary treatment, but potentially digestible fiber (NDF - indigestible residue) was higher in low NFC diets (26.7 ± 2.33) than high NFC diets (23.0 ± 2.33) (Table 3). This would be expected, as most of the dietary fiber was supplied by the forage.

Milk fat % and milk true protein % were not affected by carbohydrate source, but milk fat % was lower and milk true protein % was higher in high NFC treatments. Ruiz et al. (1995) reported that milk fat concen-

tration did not change as level of forage in the diet increased, but that milk protein concentrations decreased linearly as dietary NDF increased. Ruiz et al. (1995) attributed these decreases in milk protein to a decrease in nonfibrous carbohydrates, which likely stimulated lower microbial yields, leading to lower milk protein concentration. Lower milk fat % in the high NFC diets, coupled with higher milk production in these diets, resulted in no differences in energy-corrected milk due to NFC level or source. Milk lactose % was higher in high NFC diets and also slightly higher with sucrose treatments. Milk urea nitrogen was higher in cows fed sucrose treatments and in cows fed low NFC diets. Yield of fat was not influenced by source or level of NFC, due to higher fat% and lower DMI of cows on low NFC diets vs. those cows on high NFC diets (Table 4). Protein and lactose yield were lower for cows fed low NFC diets than those cows fed high NFC diets due to both lower DMI and lower protein% and lactose% in cows fed low NFC diets.

Nitrogen Balance

MacRae et al. (1993) indicated that conventional nitrogen balance studies result in an overestimation of N retained of about 20 to 25%. Studies with humans have also demonstrated that N balance studies overestimate N retention, and that the overestimates could not be accounted for by incomplete recovery of excreted N (Hegsted, 1976; Young, 1986). Spanghero and Kowalski (1997) suggested that even with corrections for volatile ammonia losses in urine and feces, and corrections for scurf and conceptus, there are likely to be

Table 4. Least squares means for intake, digestibility, milk yield, and the composition and yield of milk components.

Variable	Diet ¹				SE	Contrast ²		
	HNFCN ¹	HNFCS	LNFCN	LNFCS		Sucrose	Forage	S × F
Milk, kg d ⁻¹	39.8	39.5	37.8	38.9	0.88	0.28	0.02	0.14
ECM ³	33.8	33.8	33.5	32.7	0.78	0.52	0.31	0.59
Dry matter intake, kg d ⁻¹	21.7	21.4	20.1	20.6	0.62	0.68	0.01	0.15
FNDF intake, % of BW ⁴	1.06	1.09	1.38	1.24	0.064	0.39	0.01	0.19
Feed efficiency ⁵	1.60	1.58	1.63	1.65	0.043	0.87	0.18	0.62
Milk fat, %	3.24	3.27	3.44	3.47	0.120	0.69	0.05	0.99
Milk true protein, %	2.58	2.59	2.52	2.49	0.047	0.58	0.01	0.36
Milk lactose, %	4.80	4.82	4.73	4.76	0.032	0.02	0.01	0.59
Milk urea nitrogen, mg/dl	13.39	14.46	16.96	17.48	0.503	0.01	0.01	0.49
Yield, kg d ⁻¹								
Fat	1.28	1.29	1.30	1.33	0.046	0.53	0.56	0.77
Protein	1.02	1.02	0.95	0.97	0.023	0.64	0.01	0.34
Lactose	1.92	1.89	1.80	1.84	0.039	0.68	0.01	0.21

¹HNFCN = high NFC (nonfibrous carbohydrate), no sucrose; HNFCS = high NFC, sucrose; LNFCN = low NFC, no sucrose; LNFCS = low NFC, sucrose.

²Contrast compares effect of carbohydrate source (sucrose or no sucrose) and forage level (47 or 58% of diet) and the interaction between carbohydrate source and forage level (S × F).

³Energy-corrected milk = ECM (kg d⁻¹) = [(41.63 × milk fat % + 24.13 × milk protein % + 21.60 × milk lactose %) × milk (kg d⁻¹)]/340 (Tyrell and Reid, 1965).

⁴Forage NDF intake, expressed as a % of BW.

⁵Feed efficiency = ECM/DMI intake.

other sources of losses. They suggested possible losses coming from gaseous N products, nitrification processes in the digestive tract or nitrate components in feeds and feces that are not accounted for. As such, our comparisons among treatments for N retention data should be considered relative.

Our observations for N balance data are consistent within the ranges reported in the literature for these values (Spanghero and Kowalski, 1997). Total N consumed was greater for cows offered high NFC treatments (Table 5), attributable to higher total DMI (Table 4). Milk N output was also greatest for cows offered high NFC treatments, although there was a significant source × forage interaction. Cows offered the high NFC diet with corn had lower milk N than those cows offered the high NFC diet with sucrose ($P = 0.042$). Conversely, cows offered the low NFC diet with corn had higher milk N than those cows offered the low NFC diet with sucrose ($P < 0.01$). Within forage levels, cows offered the high NFC diet with sucrose had much higher milk N than cows offered low NFC diet with sugar ($P < 0.01$), whereas there was no difference ($P = 0.394$) in milk N between cows offered high NFC and low NFC with corn. Nitrogen use efficiency (milk N/intake N) was higher in cows offered high NFC diets. The range in nitrogen use efficiencies for the treatments (25.1 to 27.5%) is consistent with the mean observed in other studies (Jonker et al., 1998; Castillo et al., 2001).

Cows on the low NFC diets had greater daily urine output than the urine output of cows on the high NFC diets (32.4 ± 2.23 vs. 25.3 ± 2.23 kg/d; Table 5). Increased forage in the diet has been reported to increase urinary water loss (Dahlborn et al., 1998). Also, Holter and Urban (1992) observed that urine production increased osmotically because of higher N content of diet.

Fecal nitrogen output did not differ between NFC levels when no sucrose was in the diet ($P = 0.992$), but was greater in the high NFC diet with sucrose than the low NFC diet with sucrose ($P < 0.01$). The difference between the sucrose diets may have been due to the lower N intake of the low NFC diet. Overall fecal N expressed as a percentage total N intake was not different among diets. This is to be expected, as digested nitrogen in the diet in excess of cow maintenance and growth requirements is excreted through milk and urine, and N in feces, expressed as a percentage of N intake is relatively constant (Castillo et al., 2001).

Nitrogen retention was greater for cows consuming high NFC (low NDF) diets than for those offered low NFC (high NDF) diets (Table 5). Nitrogen retention was also greater for cows offered corn treatments than those consuming the sucrose treatments. The difference in nitrogen balance between cows consuming corn and sucrose was greater for cows on high NFC treatments than those on the low NFC diet. Similar observations were noted when retained nitrogen was expressed as a percentage of N intake. Higher N reten-

Table 5. Relative nitrogen balance least square means as influenced by diet (n = 8).¹

Variable	Diet ²				SE	Contrast ³		
	HNFCN ¹	HNFCS	LNFCN	LNFCN		Sucrose	Forage	S × F
Intake N, g/d	673	665	665	623	36.5	0.09	0.02	0.22
Milk N, g/d	171	181	167	154	8.4	0.53	0.01	0.01
Fecal N, g/d	176	191	178	163	10.8	0.95	0.03	0.01
Urine N, g/d	237	264	296	289	16.9	0.25	0.01	0.14
N Retained, g/d ⁴	66	21	17	5	14.4	0.04	0.03	0.24
Milk N/Intake N, %	25.8	27.5	25.1	24.8	0.75	0.18	0.02	0.15
Urine N/Intake N, %	36.0	38.7	44.7	47.4	1.88	0.14	0.01	0.98
Fecal N/Intake N, %	26.5	29.0	26.5	26.0	0.92	0.17	0.09	0.10
Retained N/Intake N, %	9.6	2.6	1.7	-0.1	2.41	0.06	0.04	0.28

¹Nitrogen balance and retention was calculated from individual intakes and outputs. This included CP analysis for each individual animal's diet.

²HNFCN = high NFC (nonfibrous carbohydrate), no sucrose; HNFCS = high NFC, sucrose; LNFCN = low NFC, no sucrose; LNFCN = low NFC, sucrose.

³Contrast compares effect of carbohydrate source (sucrose or no sucrose) and forage level (47 or 58% of diet) and the interaction between carbohydrate source and forage level (S × F).

⁴N retained data also contained a correction for scurf, estimated as $0.3 \times \text{BW}^{0.60}$ (NRC, 2001). Data was not corrected for conceptus, as all cows were either not pregnant or in the first few weeks of pregnancy, when requirements for the conceptus would be less than 2 g N/d (Spanghero and Kowalski, 1997).

tion of cows offered high NFC diets vs. those offered low NFC diets was due to higher N intakes and lower urine N outputs of cow on high NFC diets (Table 5). Lower N intakes may have been due to NDF levels of the diets, which resulted in DM intakes for cows fed the low NFC diet (high NDF) (Table 3). Kaufmann and St.-Pierre (2001) reported that NDF levels (30 and 40%) had no effect on N balance measurements. In that trial, however, soybean hulls were used as the additional fiber source to generate higher fiber diets. Soybean hulls, with their high fiber digestibility and small particle size, are more likely to be digested more quickly than the fiber in this study. In addition, NFC levels were all above 35% in that study (Kaufmann and St.-Pierre, 2001), whereas in our study, NFC in the low NFC diets were approximately 31%. This lower level of NFC may have resulted in a less efficient rumen microbial N conversion in cows offered the low NFC diets. This is supported by higher MUN and urine N of cows offered these diets. Aldrich et al. (1993) noted that microbial N synthesis was higher when high ruminally available protein was fed in combination with high ruminally available NSC than when fed with lower available NSC.

Hoover and Webster (2001), in a review of in vitro and in vivo data on soluble carbohydrates, suggest that a high proportion of a very soluble carbohydrate, such as sucrose, leaves the rumen before fermentation with the liquid fraction and thus cannot contribute to microbial protein production. They based this theory on data of Henning et al. (1993) that indicated that sugar content can persist in rumen fluid for several hours after eating and that the disappearance rate

of sugar was $69\% \text{ h}^{-1}$. Dehareng and Godeau (1989) reported that the rumen fluid dilution rate in lactating cows immediately after eating approached $30\% \text{ h}^{-1}$ with DMI of 20 to 22 kg, similar to our study. Hoover and Webster (2001) postulate that because this sugar would be associated with the liquid fraction, it would leave the rumen before it could be utilized there.

CONCLUSIONS

The influence of level and source of NFC on milk production and composition was evaluated. Cows offered the higher level of NFC, had milk with lower fat, higher protein and sucrose, and lower MUN than those cows offered the lower fiber diets. Feeding diets with higher fiber levels resulted in lower efficiency of N utilization (expressed as milk N/intake N) than did feeding lower fiber levels. Replacing 10% of high-moisture corn with sucrose had little influence on milk production and composition, other than increasing lactose and MUN levels. The higher sucrose diets did, however, tend toward lower efficiency of N retention than did the lower sucrose diets ($P = 0.06$). This was observed even with the higher fiber diet. The implications of this research suggest that replacing high-moisture corn with sucrose is not an effective strategy for increasing NFC in the diets of cows fed grass silage TMR. The practice could also have negative environmental impacts, due to a reduction in N use efficiency and N retained.

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