Effects of Feeding Diets Based on Silage from Corn Hybrids that Differed in Concentration and In Vitro Digestibility of Neutral Detergent Fiber to Dairy Cows¹

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ABSTRACT

A dual-purpose hybrid and a hybrid selected for high neutral detergent fiber (NDF) concentration were harvested as corn silage. The dual-purpose silage (DPCS) had 42% NDF and 35.4% in vitro (30 h) NDF digestibility and the high fiber silage (HFCS) had 49% NDF and 40.1% in vitro NDF digestibility. Two diets (dry matter basis) had 45% DPCS or HFCS and 46% corn grain-based concentrate (dietary NDF was 29 and 32%, respectively), a third diet had 33% HFCS and 58% corn-based concentrate (27% dietary NDF), and a fourth diet had 33% DPCS and 58% concentrate that contained soybean hulls (32% dietary NDF). All diets contained 9% alfalfa silage. Diets were fed to eight midlactation Holstein cows in a 4 × 4 Latin square with 28 d periods. No differences among treatments were observed for milk yield (34.1 kg/d), dry matter intake (23.7 kg/d), and yield and concentration of milk protein. Cows fed the diet with 33% HFCS tended to have lower milk fat percentage than cows fed the 45% DPCS diet. Total digestible nutrients (measured using total collection) tended to be lower for the 33% DPCS diet than for the 45% DPCS diet. In vivo digestibility of NDF tended to be lower for the 33% HFCS diet than the 45% DPCS diet, but digestibility of starch in the two diets with HFCS was higher than the 45% DPCS diet. The lack of any substantial differences in responses suggest that the HFCS was equal to the DPCS when fed at 45% of the diet dry matter (53.5% total forage). When HFCS replaced DPCS so that NDF was similar between diets, milk fat percentage was reduced and ruminal propionate was increased. Increasing dietary NDF by adding soybean hulls to a diet based on DPCS reduced digest-

ibility of dry matter, organic matter, and protein, and resulted in lower energy balance than the 45% DPCS diet.

(**Key words:** corn silage, hybrids, digestibility, fiber)

Abbreviation key: DPCS = dual-purpose corn silage; HFCS = high fiber corn silage; IVNDFD = in vitro NDF digestibility; NFC = nonfiber carbohydrates.

INTRODUCTION

Corn silage is a major source of NDF and NE_L for many dairy cows. Increasing the concentration of NDF of corn silage could mean that lesser amounts of other forages would have to be grown or purchased by the dairy farmer to meet NDF requirements (NRC, 2001). However, corn hybrids with higher NDF concentrations are not commercially available on a widespread basis probably because whole plant NDF concentration is negatively correlated with grain yield (Cox et al., 1994), in vitro DM digestibility (Cox et al., 1994; De Boever et al., 1996), and in vivo (measured in sheep fed essentially all corn silage at approximately maintenance intakes) DM digestibility (Aufrere et al., 1992; De Boever et al., 1996). Conversely, whole plant NDF concentration is not correlated with corn silage DM yield (Cox et al., 1994). In addition, in vitro and in vivo (measured at low DMI) digestibilities might not represent digestibility in cows at high DMI. Tine et al. (2001) using brown midrib corn silage, showed clearly that extrapolating digestibility data obtained from cows at maintenance intakes to cows at productive intakes is not appropriate. In that study, hybrid differences were found for measured TDN and metabolizable energy concentrations when diets of essentially all corn silage were fed to dry cows at maintenance, but no differences were observed when silages were fed as part of a mixed diet (60% silage DM, 40% concentrate DM) fed at 4× maintenance.

Corn silage hybrids with higher than typical NDF concentrations could have economic value as a fiber source, but that value would be reduced or eliminated

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if the higher NDF concentration resulted in lower digestibility and lower available energy concentrations. An alternative method of increasing the NDF concentration of a diet is to include a nonforage fiber source such as soybean hulls (Grant, 1997).

The objective of this experiment was to compare the nutrient value of a diet with a conventional corn silage hybrid to diets with a corn silage hybrid selected to have higher NDF concentrations and in vitro NDF digestibility (IVNDFD) when substituted to provide equal corn silage DM or equal total NDF. A fourth diet that contained conventional corn silage and soybean hulls was included to help determine whether any possible treatment effects were caused by changes in dietary NDF independent of hybrid.

MATERIALS AND METHODS

Silages

A dual-purpose hybrid (B52-B2, Syngenta Seeds Inc., Golden Valley, MN) and a hybrid bred to have higher NDF concentrations and IVNDFD (N48-V8, Syngenta Seeds, Inc.) were planted on April 29, 1999 in similar fields located at the Ohio Agricultural Research and Development Center in Wooster. Seeding rate for both hybrids was 12,000 seeds/ha, and agronomic practices were identical for each field. On September 13, 1999, the dual-purpose hybrid was harvested and put into a glass-lined steel silo (Harvestore, A.O. Smith Corp. Milwaukee WI). The following day, the other hybrid was harvested and put in a similar silo. Both hybrids were at the one-half milk stage at harvest and were chopped at 0.95 cm theoretical length of cut using the same harvester without kernel processing. The silages remained undisturbed for about 4 mo.

Cows and Diets

Eight multiparous Holstein cows at 174 DIM (SD = 20) at the start of the experiment were randomly assigned to one of four treatment sequences in a 4 × 4 Latin square with 28-d periods. Cows were housed in individual tie stalls, fed once daily and milked twice daily. Diets were fed as TMR for 5 to 10% feed refusal per day. Milk weights were recorded electronically at each milking, and amount of feed offered and refused was measured daily. Cows were weighed approximately 4 h after feeding at the start of the experiment and then every 28 d. Body condition was scored (Wildman et al., 1982) by two independent evaluators at the start of the experiment and then every 28 d.

During the last week of each period, digestibility was measured by total collection of feces and urine for 4 d (Weiss and Wyatt, 2000). Only six metabolism stalls

Table 1. Ingredient composition of the diets (% of DM).

	Diet			
	45% DPCS	45% HFCS	33% DPCS	33% HFCS
Alfalfa silage	8.90	8.90	8.90	8.90
Dual purpose corn silage (DPCS)	44.60	...	33.00	...
High fiber corn silage (HFCS)	...	44.60	...	33.00
Ground corn	23.19	23.19	20.32	34.88
Soybean hulls	...	...	16.44	...
Soybean meal, 44% CP	17.32	17.32	15.23	17.11
Tallow	1.40	1.40	1.40	1.40
Molasses, dried	0.93	0.93	0.94	0.94
Fish meal, menhaden	0.42	0.42	0.42	0.42
Blood meal, ring-dried	0.42	0.42	0.42	0.42
Limestone	1.00	1.00	1.09	1.09
Sodium bicarbonate	0.79	0.79	0.80	0.80
Mineral/vitamin premix ¹	1.03	1.03	1.04	1.04

¹Contained 29.05% trace mineral salt, 23.27% dicalcium phosphate, 11.60% magnesium oxide, 9.70% Dynamate (IMC Global, Lake Forest, IL), 13.80% sodium selenate premix (200 mg Se/kg), 0.46% copper sulfate, 0.46% zinc oxide, 2.00% vitamin A premix (30,000 IU/g), 4.14% vitamin D premix (3000 IU/g), and 5.52% vitamin E premix (44 IU/g).

are available at our facility therefore a different experimental design was used. During each period of the Latin square, six of the eight cows were moved to metabolism stalls. A total of 24 (6 cows × 4 periods) collections were made; all cows were in the metabolism stalls three times, and four observations per diet were made. All diets were fed in each collection period (two diets fed to one cow each and two diets fed to two different cows in each period).

Four diets (Tables 1 and 2) were formulated that varied in corn silage hybrid and source and concentra-

Table 2. Nutrient composition of the diets (DM basis).

	Diet ¹			
	45% DPCS	45% HFCS	33% DPCS	33% HFCS
DM, % as fed	62.8	62.8	69.0	68.3
CP, %	17.5	17.5	17.3	17.3
NDF, %	28.9	31.9	31.6	27.6
Forage NDF, %	23.2	25.1	18.1	20.4
Corn silage NDF, % of NDF	64.8	68.5	44.3	58.6
Starch, %	25.4	22.3	23.4	29.5
Corn silage starch, % of starch	36.2	27.8	29.1	15.6
Nonfiber carbohydrates ² , %	43.9	41.4	40.2	45.8
Fatty acids, %	4.6	4.4	4.4	4.6
Ca, %	0.80	0.80	0.84	0.83
P, %	0.38	0.38	0.38	0.37
Mg, %	0.25	0.25	0.26	0.24

¹Diets: 45% DPCS = TMR with 45% dual purpose corn silage (DPCS) and 46% corn-based concentrate; 45% HFCS = TMR with 45% high fiber corn silage (HFCS) and 46% corn-based concentrate; 33% DPCS = TMR with 33% DPCS and 58% concentrate that contained soybean hulls; 33% HFCS = TMR with 33% HFCS and 58% corn-based concentrate.

²Nonfiber carbohydrates = OM – CP – NDF – fatty acids.

tion of NDF. Diet 1 was formulated to contain 45% dual-purpose corn silage (**DPCS**) and 46% concentrate (predominately corn grain and soybean meal). Diet 2 was the same as diet 1 except that the high fiber corn silage (**HFCS**) replaced the DPCS. Diet 2 was formulated to have higher concentrations of total and forage NDF than diet 1. Diet 3 contained 33% HFCS and 58% concentrate (similar to the concentrate used in diet 1) and was formulated to provide the same concentration of total NDF as diet 1. Diet 4 contained 33% DPCS and 58% concentrate that contained soybean hulls to make dietary NDF concentration equal to that in diet 2.

Sampling and Analyses

While the corn was being harvested, ears from ten random plants were collected from each field and hand-shelled, and the grain was analyzed for DM (100°C overnight). Milk samples (a.m. and p.m.) were taken once each week and analyzed for fat and CP per approved procedures (AOAC, 1990) with a B2000 Infrared Analyzer (Bentley Instruments, Chaska MN) by Ohio DHI Cooperative, Inc. (Powell, OH). Silage samples were taken weekly and analyzed for DM by drying overnight at 100°C to adjust diets for changes in DM. During the digestion trials, silages and concentrates were sampled daily and composited by period. The composited and weekly samples were dried at 60°C and ground through a 2 mm screen (Wiley Mill, Arthur H. Thomas, Philadelphia, PA). Feed samples were analyzed for NDF (Procedure A; Van Soest et al., 1991) with sodium sulfite and amylase (Sigma A3306, Sigma Diagnostics, St. Louis, MO), ash, CP ($N \times 6.25$), ADF, and sulfuric acid lignin (AOAC, 1990), and starch, fermentation acids, and fatty acids (Weiss and Wyatt, 2000). The composited corn silage samples were analyzed for IVNDFD (Goering and Van Soest, 1970). The four composited samples of each silage were incubated in rumen fluid and buffer in triplicate for either 30 or 48 h in a single run. Rumen fluid was collected from a single cow fed a diet of approximately 35% alfalfa silage, 15% corn silage, 28% ground corn, 6% soybean hulls, 7% roasted whole soybeans, and 9% protein and mineral mix (DM basis). The composition data in Table 3, except for NDF and starch, are means of the four composited samples. In addition to the four composited samples, weekly and every other week samples were analyzed for NDF and starch, respectively. During the third and fourth week of each period, two additional samples (on consecutive days) of the corn and alfalfa silages were collected, and particle size distribution was determined (Lammers et al., 1996). Samples from the middle screen and from the pan were collected (8 samples of each silage) and analyzed for starch as described above.

During the digestion trial, daily samples of feces and orts were composited within cow and analyzed for ash, CP, NDF, starch, and fatty acids as described above. Daily milk and urine samples (pH kept <5 with HCl) were composited and analyzed for N as described above. During the last week of each period (but not during the digestion trial), rumen fluid was obtained via stomach tube from each cow approximately 4 h after feeding. The samples were immediately acidified and frozen until analyzed for VFA by GLC (Supelco, 1975).

Statistical Analyses

Mean (by cow) milk production, milk composition, and DMI were calculated from data collected during the last 2 wk of each period. The BW and BCS for each cow at the end of each period were analyzed statistically. Change in BW and BCS were calculated as the difference between the BW or BCS at the end of each period and the BW or BCS at the end of the preceding period. Apparent digestibilities of nutrients were calculated as nutrient intake minus fecal output divided by intake. The TDN (% of DM) was calculated as concentration (% of DM) of digestible CP + digestible NDF + digestible nonfiber carbohydrate + (digestible fatty acids $\times 2.25$), where nonfiber carbohydrate (**NFC**) = OM - CP - NDF - fatty acids. The experimental design for production and rumen VFA data ($N = 32$) was a replicated 4×4 Latin square. These data were analyzed using Proc MIXED (SAS, 1999) with a model that included square (random, 1 df), cow within square (random, 6 df), period (3 df), square $\times$ period (random, 3 df), treatment (3 df), and error (15 df). The experimental design for the digestibility data ($N = 24$) was an incomplete Latin square. The MIXED procedure of SAS was used and the model included cow (random, 7 df), period (3 df), treatment (3 df), and error (10 df). For all measures, the 45% DPCS diet was designated as the standard diet (i.e., control) and three single degree of freedom contrast were used to compare the other three diets to the standard diet. The comparison between the standard diet (45% DPCS diet) and 45% HFCS diet was used to evaluate hybrid difference when dietary concentration of corn silage was constant (diets differed in total NDF concentration). The comparison between the standard diet and 33% HFCS diets was used to evaluate hybrid differences when dietary concentrations of total NDF were held constant (diets differed in concentration of corn silage). The comparison between the standard diet and the 33% DPCS diet was used to evaluate the effect of increasing dietary NDF using soybean hulls rather than a different corn silage hybrid. Particle size data and IVNDFD of the two hybrids were

Table 3. Nutrient composition of the silages fed during the trial (DM basis).

	Corn silage hybrid ¹		Alfalfa silage
	DPCS	HFCS	
DM, % as-fed	38.0	38.1	53.1
OM, %	96.0	95.9	90.0
CP, %	8.6	8.5	20.4
NDF, %	42.4	49.0	47.2
ADF, %	24.3	26.0	36.8
Lignin, %	2.5	2.6	7.0
Starch, %	20.3	15.9	1.4
Fatty acids, %	3.0	2.6	2.0
IVNDFD-30 h ² , %	35.4*	40.1*	ND
IVNDFD-48 h ² , %	41.5**	46.3**	ND
pH	3.86	3.95	5.33
Acetic acid, %	2.3	2.0	2.0
Butyric acid, %	0.2	0.2	0.2
Lactic acid, %	4.5	4.1	2.3
Particle size distribution of DM ³ , % of total DM			
Top	1.2	2.1	8.3
Middle	44.5	46.1	45.0
Pan	55.3	51.8	46.7
Particle size distribution of starch ³ , % of total starch			
Middle	69.4	64.8	ND
Pan	30.6	35.2	ND

* $P < 0.05$; ** $P < 0.01$.¹DPCS = dual purpose corn silage; HFCS = high fiber corn silage.²In vitro rumen digestibility of NDF after 30 or 48 h incubation. Standard error for four separate in vitro runs per silage was 1.3 (30 h) and 0.8 (48 h). ND = not determined.³Measured using a two screen sieve plus a pan (Lammers et al., 1996).

compared with a *t*-test; different samples from the same silo (4 samples/hybrid) provided the experimental error.

RESULTS

The growing season was drier and hotter than normal (Table 4). Silage DM yields were 15,900 kg/ha for the DPCS and 16,100 kg/ha for the HFCS (because plots were not replicated yields were not compared statistically). Concentrations of CP, fatty acids, ash, and fermentation acids were similar for the two hybrids (Table 3). Mean NDF concentration was 6.6 percentage units higher and mean starch concentration was 4.4 percent-

age units lower for HFCS. Concentrations of NDF and starch in the silages were variable over time (Figure 1). The IVNDFD (30 and 48 h) was higher ($P < 0.05$) for the HFCS (Table 3). Particle size distribution of starch and DM were not different among hybrids ($P > 0.12$).

Table 4. Climatic conditions during the 1999 growing season¹.

Month	Temperature, °C		Precipitation, mm	
	Mean	Deviation ²	Total	Deviation ²
March	1.1	-2.3	45	-29
April	10.6	2.0	159	81
May	16.1	1.3	61	-41
June	20.6	1.2	34	-55
July	23.3	1.7	113	10
August	19.4	-0.9	86	-8
September	16.1	-0.8	61	-21

¹Data collected from a weather station located approximately 2 km from the plots.²Deviation = actual minus 30-yr monthly average. **Figure 1.** Concentrations of NDF (triangles) and starch (circles) in corn silage from a dual purpose hybrid (solid symbols) or a hybrid selected for high NDF concentration (open symbols). Each symbol represents a single sample taken from a single silo.

Table 5. Production by cows fed diets containing different corn silage hybrids.

	Diet ¹				SE
	45% DPCS	45% HFCS	33% DPCS	33% HFCS	
Dry matter intake, kg/d	23.9	23.7	23.4	23.7	1.2
Milk, kg/d	33.3	34.0	33.8	35.5	1.3
4% FCM, kg/d	33.3	33.3	33.6	33.5	1.9
Milk fat, %	3.93	3.82	3.95	3.53*	0.22
kg/d	1.33	1.32	1.34	1.29	0.10
Milk protein, %	3.31	3.27	3.27	3.30	0.08
kg/d	1.12	1.11	1.11	1.17	0.05
BW, kg	673	675	666*	669	16
BW change, kg/28 d	15	14	4*	17	4
BCS	3.0	3.0	2.9	2.9	0.1
BCS change (unit/28 d)	0.1	0.0	0.1	0.1	0.1
NE _L balance ² , Mcal/d	3.7	2.7*	2.1**	3.2	1.6

***Mean differs from 45% DPCS diet ($P < 0.10$) or ($P < 0.05$), respectively.

¹Diets: 45% DPCS = TMR with 45% dual purpose corn silage (DPCS) and 46% corn-based concentrate; 45% HFCS = TMR with 45% high fiber corn silage (HFCS) and 46% corn-based concentrate; 33% DPCS = TMR with 33% DPCS and 58% concentrate that contained soybean hulls 33% HFCS = TMR with 33% HFCS and 58% corn-based concentrate.

²Calculated by entering diet composition and individual BW, milk yield and composition and DMI for each cow (within a period) into the NRC (2001) model.

Dry matter intake and yields of milk, 4% FCM, milk fat, and milk protein were not affected by treatment (Table 5). Milk fat percentage tended to be lower ($P < 0.07$) for cows fed the 33% HFCS diet than for cows fed the 45% DPCS diet. Based on changes in BW, all cows were in positive energy balance, however, cows fed the 33% DPCS diet (contained soybean hulls) gained less ($P < 0.06$) BW than cows fed 45% DPCS diet. Net energy balance, as estimated by NRC (2001) which does not incorporate changes in BW was in agreement with the lower change in BW for the 33% HFCS diet. Calculated NEL balance was lower ($P < 0.08$) for the 45% HFCS diet compared with the 45% DPCS diet, but BW change was similar for those two diets. The NRC model overestimated NEL balance for the 45% DPCS diet, underestimated NEL balance for the 45% HFCS diet, or some combination of both.

During the digestion trials, DMI was approximately 3.8× maintenance and was not affected by treatment (Table 6). The mass of wet feces excreted averaged 50.4 kg/d (SE = 3.0) and urine excretion averaged 22.9 L/d (SE = 1.9); neither were affected by treatment (data not shown). Nitrogen excretion via urine averaged 217 g/d (SE = 14) and was not affected by treatment (data not shown). Nitrogen balance averaged 34 g/d (SE = 13) and was not affected by treatment (data not shown).

The only differences in digestibility observed between the standard diet (45% DPCS) and the 45% HFCS diet were higher NFC ($P < 0.03$) and starch ($P < 0.02$) digestibilities for the 45% HFCS diet (Table 6). The 33% HFCS diet had lower NDF digestibility ($P < 0.02$) and higher NFC ($P < 0.01$) and starch ($P < 0.01$) digestibilities than

the 45% DPCS diets. The diet with 33% DPCS and soybean hulls had lower DM ($P < 0.05$), OM ($P < 0.07$), and CP ($P < 0.02$) digestibilities than the 45% DPCS diet. Measured TDN concentration of the 33% DPCS diet tended ($P < 0.10$) to be lower than the TDN of the 45% DPCS diet.

Diet NE_L concentration was calculated using: 1) measured TDN concentration and equations (NRC, 1989, 2001); 2) the NRC (2001) model; and 3) summing NE_L used for maintenance, BW change, and milk production (NRC, 2001) and dividing by DMI. The three methods produced similar estimated NE_L concentrations (Table 6) and differences among diets were generally small.

The ruminal VFA profile was not different between the standard diet (45% DPCS) and the 45% HFCS diet or the 33% DPCS diet (contained soybean hulls). Cows fed the 33% HFCS diet had higher ($P < 0.05$) molar proportion of propionate than did cows fed the standard diet.

DISCUSSION

Differences between the hybrids for concentrations of NDF and starch and IVNDFD were as expected (Table 3). Starch concentrations for both hybrids, however, were lower than expected. For both silages, the sum of the concentrations of NDF, ash, CP, fatty acids, starch, and organic acids was approximately 87%. The reason why that value is not closer to 100% is unclear. The composition of the unaccounted mass is unknown but it could be soluble fiber, fructose, sucrose, and other compounds. For a variety of hybrids and agronomic

Table 6. Intake during digestion trial and digestibility of nutrients in diets with different corn silage hybrids (DM basis).

	Diet ¹				SE
	45% DPCS	45% HFCS	33% DPCS	33% HFCS	
DMI, kg/d	24.3	24.3	24.8	23.8	1.2
Digestibility, %					
DM	65.8	65.0	63.9*	65.5	1.2
OM	67.0	66.3	65.2*	66.7	1.1
CP	67.2	66.0	64.6**	66.5	1.1
NDF	42.2	39.6	41.1	35.6**	3.0
Starch	88.7	91.7**	90.4	93.0**	1.1
Nonfiber carbohydrates	82.3	85.1**	82.4	86.7**	1.4
Fatty acids	70.6	74.7	75.5	72.8	3.5
TDN	67.4	67.0	66.0*	67.6	1.1
Estimated NE _L , Mcal/kg					
Calculated from TDN ²	1.62	1.61	1.57	1.63	...
NRC (2001) ³	1.64	1.63	1.63	1.65	...
Energy use/DMI ⁴	1.59	1.60	1.55	1.62	...

***Mean differs from 45% DPCS diet ($P < 0.10$) or ($P < 0.05$), respectively.

¹Diets: 45% DPCS = TMR with 45% dual purpose corn silage (DPCS) and 46% corn-based concentrate; 45% HFCS = TMR with 45% high fiber corn silage (HFCS) and 46% corn-based concentrate; 33% DPCS = TMR with 33% DPCS and 58% concentrate that contained soybean hulls; 33% HFCS = TMR with 33% HFCS and 58% corn-based concentrate.

²NE_L calculated from TDN: Digestible energy (DE) = TDN $\times$ 0.04409; Metabolizable energy (ME) = 1.01 $\times$ DE - 0.45; NE_L = 0.709 $\times$ ME - 0.19 (NRC, 1989, 2001).

³Calculated (NRC, 2001) using individual cow data and actual diet composition.

⁴Sum of NE_L requirements for maintenance, milk production and BW change (NRC, 2001) divided by DMI.

practices, starch concentrations for corn silage have ranged from 26 to 37% of DM (Bal et al., 1997; Bal et al., 2000b; Weiss and Wyatt, 2000). The DPCS in this study averaged 20.3% starch (Table 3). To verify our starch assay, samples of dry corn, high moisture corn, and corn silage from previous experiments were assayed for starch at the same time as samples from the current experiment. Starch concentrations from all samples except the two silages in this experiment were as expected. A probable reason for the low starch concentrations was the dry and hot conditions experienced during the growing season (Table 4). Drought-stress can cause repartitioning of carbohydrates in corn plants resulting in higher fructose and glucose concentration in leaves (Schellenbaum et al., 1998). Frederick et al. (1990) reported significant reductions in kernel weight for drought-stressed corn compared with irrigated corn (43 vs 52% of whole plant DM).

Although DMI was not affected by treatment (Table 5), the diets differed in at least two factors that have been related to DMI (i.e., NDF concentration and IVNDFD). Oba and Allen (1999b, 2000) reported that a 1-unit increase in IVNDFD of brown midrib corn silage was associated with an average 0.15 kg/d increase in DMI. In our study, IVNDFD of the HFCS was 4.7 percentage units higher than the DPCS (Table 3), which according to Oba and Allen (1999b, 2000) should have

resulted in an increase in DMI of about 0.7 kg/d. That change is less than the standard error for DMI in our study. However, the lack of even a numerical trend toward higher DMI for the silage with higher IVNDFD and data showing higher DMI for cows fed a hybrid with lower in situ NDF digestibility (Valentin et al., 1999) suggest that factors in addition to in vitro (or in situ) NDF digestibility need to be considered. In the current experiment and in the Valentin et al. (1999) study the hybrids with higher in situ or in vitro NDF digestibility also had higher NDF concentrations than the control hybrids. The concentration of indigestible NDF (i.e., NDF concentration $\times$ in vitro or in situ indigestibility) in a forage may be important. Dry matter intake was higher for cows fed a diet based on a corn silage hybrid with a lower concentration of indigestible (measured in situ) NDF (Valentin et al., 1999). In our study the difference between silages for IVNDFD was 4.7 percentage units but the difference in the concentration of 30 h indigestible NDF was only 2 percentage units.

The NDF content of the hybrids differed by 6.6 percentage units (Table 3) and total dietary NDF ranged from about 27 to 32% (Table 2). In most of the 15 papers reviewed by Allen (2000), DMI increased as the concentration of NDF in the diet decreased when dietary NDF was altered by changing the forage to concentrate ratio.

Table 7. Ruminal VFA (moles/100 moles of total VFA) for cows fed different corn silage hybrids.

	Diet ⁴				SE
	45% DPCS	45% HFCS	33% DPCS	33% HFCS	
Acetate	59.4	59.1	60.4	57.5	1.5
Propionate	21.8	22.6	21.0	24.1**	1.2
Butyrate	14.6	14.3	14.6	14.0	0.8
Acetate:Propionate	2.74	2.67	3.02	2.49	0.26

**Mean differs from 45% DPCS diet ($P < 0.05$).

¹Diets: 45% DPCS = TMR with 45% dual purpose corn silage (DPCS) and 46% corn-based concentrate; 45% HFCS = TMR with 45% high fiber corn silage (HFCS) and 46% corn-based concentrate; 33% DPCS = TMR with 33% DPCS and 58% concentrate that contained soybean hulls; 33% HFCS = TMR with 33% HFCS and 58% corn-based concentrate.

In the current study, dietary NDF varied because of hybrid type, concentration of corn silage in the diet, and inclusion of a nonforage fiber source. Bal et al. (2000a) compared two hybrids that contained either 32.8 (low) or 39.2% NDF (normal). In diets with 50% forage, no difference in DMI between diets was observed (total dietary NDF was 24 and 27%), but in diets with about 60% forage, cows fed the low NDF silage had lower DMI than cows fed the normal NDF corn silage (Bal et al., 2000a).

The HFCS had higher IVNDFD (Table 3), but similar or lower in vivo NDF digestibilities (Table 6) were observed for diets containing HFCS. Corn silage provided between 44 and 69% of the total NDF in each diet (Table 2); therefore, smaller differences among treatments would be expected for in vivo digestibility because of dilution. However, the differences in the amount of NDF provided by corn silage in the 45% DPCS diet and the 33% HFCS diet cannot explain the differences observed between in vitro and in vivo NDF digestibility. In vivo fiber digestibility is often reduced when excessive amounts of starch or NFC are fed (Llano and DePeters, 1985; Putnam and Loosli, 1959). The rumen VFA data (Table 7) and reduced milk fat percentage (Table 5) suggest that altered rumen conditions in cows fed the 33% HFCS diet caused the low in vivo NDF digestibility for that diet. This effect would not have occurred in vitro.

Significant correlations between in vitro DM digestibility and in vivo DM digestibility measured with sheep fed at approximate maintenance intakes have been observed ($r = 0.6$ for unfermented corn plants, Aufrere et al., 1992; and $r = 0.8$ for corn silage, De Boever et al., 1996). However, Oba and Allen (2000) reported a 9.4 percentage unit difference in 30 h IVNDFD between a brown midrib corn silage and a control silage but no difference in in vivo NDF digestibility. In another experiment with brown midrib corn silage, a 9.7 percentage unit difference in 30 h IVNDFD between hybrids was found, but in vivo NDF digestibility differed ($P <$

0.02) by only 2.2 units (Oba and Allen, 1999a). The disparity between in vitro and in vivo digestibilities in those studies was likely caused by differences in DMI. The data from our experiment and data from experiments with brown midrib corn raise concerns about using IVNDFD to estimate in vivo NDF digestibility by dairy cows fed mixed diets at higher intakes.

The reasons for improved starch digestibility by cows fed the HFCS diets (Table 6) cannot be determined unequivocally. Kernel DM was similar for the hybrids (64.5 and 63.6% for DPCS and HFCS, respectively) and probably was not different enough to affect starch digestibility. The majority of starch in all diets came from ground corn, rather than corn silage, and the amount of starch provided by the corn silage varied among treatments (Table 2). On average, more starch came from the ground corn meal in diets with the HFCS than in diets with the DPCS. The starch in the HFCS could be more digestible than starch from the DPCS or the starch from the corn meal was more digestible than starch provided by corn silage, regardless of hybrid.

The only measurements that were different between the diets with 45% DPCS and 45% HFCS was starch and NFC digestibility. These two diets contained equal concentrations of corn silage and total forage but because the HFCS had a higher concentration of NDF, the 45% HFCS diet had a higher concentration of NDF than the 45% DPCS (31.9 versus 28.9, respectively). The 33% DPCS diet included soybean hulls so that dietary NDF was equal to the 45% HFCS diet. The 33% DPCS diet had lower DM, OM, and CP digestibility, lower TDN, and resulted in lower BW gain than the 45% DPCS diet. In this experiment, increasing dietary NDF via a corn silage hybrid that had higher in vitro NDF digestibility was superior to increasing dietary NDF via soybean hulls. When the different corn silages were substituted to maintain equal dietary NDF (45% DPCS vs. 33% HFCS diets), cows fed the HFCS diet had lower milk fat percentage and higher ruminal propionate. These responses are consistent with those ob-

tained when diets with inadequate concentrations of NDF, forage NDF, or effective NDF, or excessive concentrations of NFC are fed (Armentano and Pereira, 1997; Firkins, 1997). The concentrations of total and forage NDF in the 33% HFCS diet met NRC (2001) recommendations but the concentration of NFC was higher than the NRC recommendation.

CONCLUSIONS

A diet with 45% corn silage from a hybrid selected for higher concentrations of NDF and increased in vitro NDF digestibility had similar digestibility, calculated NE_L values, and supported similar production as a diet with 45% corn silage from conventional hybrid. The higher NDF concentration in the HFCS diet did not reduce the available energy concentrations of the diets. Increased IVNDFD, however, did not result in increased DMI or increased in vivo NDF digestibility. When soybean hulls were used to increase dietary NDF (33% DPCS diet), DMI, milk yield and composition were similar to the standard diet (45% DPCS) but digestibility of several fractions and TDN was reduced resulting in reduced energy balance and less BW gain. Reduced digestibility was not observed when dietary NDF was increased by feeding HFCS. When the HFCS replaced the DPCS so that total dietary NDF was equal (33% HFCS diet vs. 45% DPCS diet) milk fat percentage and digestibility of NDF were lower and ruminal propionate was higher. These results suggest that the 33% HFCS diet was not properly balanced with respect to carbohydrate fractions.

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