Effects of varying dietary ratios of corn silage to alfalfa silage on digestion of neutral detergent fiber in lactating dairy cows

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ABSTRACT

An *in vivo* study was performed to test an *in vitro* procedure and model that predicts total-tract neutral detergent fiber (NDF) digestibility for lactating dairy cattle. Corn silage (CS) and alfalfa silage (AS) were used as forages for this study. These forages had similar NDF composition, but fiber in the CS contained less indigestible NDF compared with AS (35.5 and 47.8% of indigestible NDF, respectively). The *in vitro* method estimated rate of digestion of alfalfa potentially digestible NDF to be approximately 2 times faster than CS fiber (6.11 and 3.21%/h, respectively). Four diets were formulated containing different proportions of CS to AS: 100CS:0AS, 67CS:33AS, 33CS:67AS, and 0CS:100AS, as percentage of diet DM basis. The objective was to construct diets that contained approximately similar levels of NDF but with different pool sizes and rates of digestion of potentially digestible NDF. Diets were fed to 8 ruminally cannulated, multiparous, lactating dairy cows in a replicated 4 × 4 Latin square with 21-d periods. Total-tract fiber digestibility and fiber digestion kinetic parameters observed *in vivo* were compared with the values predicted by the *in vitro* assay and model. Total-tract NDF digestibility coefficients were similar (41.8 and 40.6% of total NDF) for the *in vitro* and *in vivo* methods, respectively. As the proportion of dietary alfalfa increased, the digestibility of NDF increased. The rate of digestion of potentially digestible NDF predicted from the *in vitro* assay was also similar to what was observed *in vivo*. Results suggest that the *in vitro* total-tract NDF digestibility model could be used to predict rate of fiber digestion and NDF digestibility for lactating dairy cattle.

Key words: digestibility of neutral detergent fiber, rate of digestion, *in vitro* prediction

INTRODUCTION

In Wisconsin and much of the United States, dairy farms are integrated cropping and animal-production enterprises. A survey of high-producing herds in the United States showed that 91% used corn silage and 58 and 81% were using alfalfa hay and alfalfa silage, respectively (Kellogg et al., 2001). Most producers prefer feeding diets with mixtures of forages rather than a single forage (Jordan and Fourdraine, 1993). High-quality alfalfa silage (AS) and high-quality corn silage (CS) typically contain similar concentrations of NDF as a percentage of DM. Goeser (2008) summarized total-tract fiber digestibility measurements that were reported in 25 CS trials (81 treatment comparisons) and more than 20 trials in which legumes and grasses (64 treatment comparisons) were the primary forages fed to high-producing ruminants. The result of this survey revealed that the total-tract NDF digestibility of CS-based diets averaged 40.2% (±8.8), whereas total-tract NDF digestibility of legume-based diets was 47.3% (±8.1). The NDF fraction of CS typically contains a higher proportion of potentially digestible NDF (pdNDF) than alfalfa NDF, but pdNDF of alfalfa typically digests faster than CS pdNDF (Goeser, 2008).

Indigestible NDF (iNDF) and digestible NDF have different ruminal kinetics (Stensig and Robinson, 1997). The pdNDF passes from the rumen at a slower rate compared with indigestible NDF (Lund et al., 2007). Ruminal fiber kinetics also differ between CS and alfalfa. Diets with a higher proportion of AS had a faster digestion rate of pdNDF (5.0–7.5%/h, Dado and Allen, 1996; Voelker Linton and Allen, 2008) than diets with more CS (2.29%/h, Oba and Allen, 2000). However, the passage rate of pdNDF was slower when diets contained a higher proportion of AS than CS (1.3%/h for AS and 3.56%/h for CS diets; Oba and Allen, 2000; Voelker Linton and Allen, 2008).

An *in vitro* model to predict total-tract NDF digestibility with accuracy needs to estimate the extent of ruminal fiber digestion, the rate of digestion of pdNDF, and the rate of passage of the pdNDF (Mertens, 2002). University of Wisconsin researchers developed a model

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that uses in vitro measures of the proportion pdNDF and rate of digestion of NDF to predict total-tract digestibility (**TTNDFD**) for lactating dairy cattle. Using these ruminal digestion parameters we hypothesized that this in vitro method would predict NDF digestibility similar to in vivo digestion. The objective of this study was to compare estimates of total-tract fiber digestibility as predicted by this in vitro TTNDFD model to in vivo measurements in lactating dairy cows fed diets that varied in proportion of CS and AS.

MATERIALS AND METHODS

Rumen and TTNDFD In Vitro Prediction

The in vitro TTNDFD model is based on the concept that fiber digestion is a 2-step process beginning in the rumen, followed by fiber digestion in the hindgut. Ruminal digestion of NDF is a time-dependent, competitive process affected by the rate of passage of pdNDF (**kp**) from the rumen, and the amount and rate of degradation (**kd**) of pdNDF, similar to the cellulose digestion model described by Waldo et al. (1972). The amount of pdNDF is calculated from the difference of total NDF and iNDF ($\text{pdNDF} = \text{NDF} - \text{iNDF}$; NRC, 2001). Indigestible NDF is determined by in vitro incubation of feedstuff in buffered rumen fluid for 240 h without rumen reinoculation by the in vitro procedure described by Goeser and Combs (2009). The rate of ruminal degradation of pdNDF (**kd**) is calculated from NDF residue measurements taken at 24, 30, and 48 h of in vitro incubation in rumen fluid (Goeser and Combs, 2009) using a first-order kinetics model with an indigestible fraction as described by Mertens (1993), which assumes that the indigestible residue does not disappear, and pdNDF residue disappears at a rate that is proportional to its mass at any time. The rate of passage of pdNDF (**kp**) is predicted from a regression model (Krizsan et al., 2010) for iNDF, which is adjusted to account for the selective retention of pdNDF (Lund et al., 2007) determined using the flux-compartment pool method described by Ellis et al. (1994). In the TTNDFD model, the predicted fiber digestibility is indexed to a 630-kg dairy cow consuming 23.4 kg/d of DM of a diet containing 30% of NDF. This index sets the **kp** of pdNDF at 2.67%/h (Lund et al., 2007; Krizsan et al., 2010).

Hindgut digestion of NDF is assumed to be 10% of total NDF digestion, which is similar to the estimate of hindgut NDF digestion in the Cornell Net Carbohydrate and Protein System Model (Fox et al., 2004). Total-tract NDF digestibility is expressed as a percent-

Table 1. Nutrient composition (mean $\pm$ SD) of silages and soy hulls

Item	Corn silage	Alfalfa silage	Soy hulls
DM, % as fed	35.2 $\pm$ 0.2	41.2 $\pm$ 1.8	90.9 $\pm$ 1.6
OM, % of DM	96.6 $\pm$ 0.4	89.3 $\pm$ 0.6	95.0 $\pm$ 0.6
CP, % of DM	6.41 $\pm$ 0.1	21.1 $\pm$ 0.2	15.0 $\pm$ 0.2
Starch, % of DM	30.0 $\pm$ 1.0	0.72 $\pm$ 0.1	—
Lignin, % of DM	2.68 $\pm$ 0.1	8.30 $\pm$ 0.2	—
Ether extract, % of DM	3.22 $\pm$ 0.1	2.88 $\pm$ 0.0	2.80 $\pm$ 0.1
Ash, % of DM	3.10 $\pm$ 0.3	11.1 $\pm$ 0.6	5.00 $\pm$ 0.2
NDF, % of DM	34.4 $\pm$ 0.8	34.7 $\pm$ 0.5	57.6 $\pm$ 0.2
iNDF, ¹ % of NDF	35.5 $\pm$ 0.2	47.8 $\pm$ 0.9	13.9 $\pm$ 0.6
pdNDF kd, ² %/h	2.69 $\pm$ 0.1	6.11 $\pm$ 0.2	7.15 $\pm$ 0.2
TTNDFD, ³ % of total NDF	36.0 $\pm$ 4.6	42.2 $\pm$ 2.3	69.7 $\pm$ 2.8

¹iNDF = indigestible NDF determined by in situ incubation for 288 h.

²pdNDF kd = potentially digestible NDF fraction digestion rate calculate from TTNDFD model.

³TTNDFD = predicted total-tract NDF digestibility using in vitro TTNDFD model.

age of total NDF: $\text{TTNDFD} = \text{pdNDF} \times [\text{kd}/(\text{kd} + \text{kp})]/0.9$.

In December of 2011, CS and AS samples were collected at the University of Wisconsin West-Madison-WI research station. The silage samples were analyzed for NDF and were also analyzed to predict TTNDFD using the in vitro model described above (Lopes et al., 2014). The CS and AS chosen for this study were selected based on adequate supply, most similar in NDF composition, and most similar in predicted TTNDFD (Table 1). The in vitro analysis indicated that CS contained less iNDF compared with AS (35.5 and 47.8% of iNDF, respectively); however, the rate of digestion of alfalfa fiber was approximately 2-times faster than CS fiber (6.11 and 3.21%/h, respectively).

Four diets were formulated containing different proportions of CS to AS: 100CS:0AS, 67CS:33AS, 33CS:67AS, and 0CS:100AS. All diets were formulated to have similar content of NDF with approximately 55% of forage and 45% of concentrate of the diet DM (Table 2). Samples of the 4 test diets were also analyzed by the in vitro method to predict TTNDFD of the complete diets (Table 3). Because the NDF of the 2 forages are similar but differ in proportion of digestible and indigestible fiber, replacing CS with AS was intended to increase the concentration of pdNDF but keep the NDF content of the diets similar. Soy hulls, which are also a source of highly digestible NDF, were included in the diets containing 67 and 100% alfalfa to allow for more corn grain in these diets.

In Vivo Trial

Eight ruminally cannulated, multiparous, Holstein cows, averaging 110 (SD $\pm$ 5) DIM and 671 (SD $\pm$ 12.5)

Table 2. Ingredient and nutrient composition of diets

Item	CS:AS ¹			
	100:0	67:33	33:67	0:100
Ingredient				
Corn silage	56.1	37.3	18.1	
Alfalfa silage	—	18.7	36.9	54.6
Dry ground shelled corn	20.0	26.5	27.9	30.8
Soybean meal (48% CP)	10.4	7.78	3.77	—
Soy hulls	—	—	3.77	6.76
Expeller soybean meal	10.8	8.17	7.91	6.76
Calcium carbonate	1.00	0.41	0.21	0.04
Sodium bicarbonate	1.00	0.58	0.56	0.21
Magnesium oxide	0.04	0.04	0.04	0.01
Mg-K-S ²	0.22	0.19	0.19	0.08
Trace mineral salt ³	0.12	0.19	0.19	0.30
Vitamin premix ⁴	0.19	0.18	0.17	0.17
AminoShure L ⁵			0.15	0.19
Smartamine M ⁶			0.19	0.02
Nutrient composition (mean $\pm$ SD)				
DM, % as fed	57.0 $\pm$ 0.1	57.8 $\pm$ 0.4	59.5 $\pm$ 0.3	60.8 $\pm$ 1.0
CP, % of DM	15.9 $\pm$ 0.1	16.3 $\pm$ 0.1	17.2 $\pm$ 0.1	18.6 $\pm$ 0.1
Starch, % of DM	32.0 $\pm$ 0.6	31.0 $\pm$ 0.3	26.0 $\pm$ 0.2	22.4 $\pm$ 0.1
NFC, % of DM	51.0 $\pm$ 0.5	48.9 $\pm$ 0.9	47.9 $\pm$ 0.9	43.9 $\pm$ 0.9
Lignin, % of DM	2.01 $\pm$ 0.1	3.01 $\pm$ 0.1	3.98 $\pm$ 0.1	5.05 $\pm$ 0.1
Ether extract, % of DM	3.35 $\pm$ 0.1	2.70 $\pm$ 0.1	2.98 $\pm$ 0.1	2.91 $\pm$ 0.1
Ash, % of DM	4.82 $\pm$ 0.2	6.60 $\pm$ 0.1	7.30 $\pm$ 0.2	9.33 $\pm$ 0.3

¹Ratio of corn silage (CS) to alfalfa silage (AS).²Dynamate (11% Mg, 18% K, 22% S; The Mosaic Co., Plymouth, MN).³Trace mineral salt = 88% NaCl; 0.002% Co; 0.2% Cu; 0.012% I; 0.18% Fe; 0.8% Mn; 0.006% Se; 1.4% Zn.⁴Vitamin A, 3,300,000 IU/kg; vitamin D, 1,100,000 IU/kg; vitamin E, 11,000 IU/kg.⁵AminoShure L, 38% lysine (Adisseo, Antony, France).⁶Smartamine M, 70% methionine (Adisseo).

kg of BW at the beginning of the trial, were randomly assigned to treatment sequence within replicate 4×4 Latin squares. Treatments periods were 21 d, consisting of 11 d of diet adaptation followed by 10 d for sample and data collection. Cows were housed in tie-stalls at the Dairy Cattle Center at University of Wisconsin–Madison. Care and handling of the animals, including ruminal cannulation, were conducted as outlined in the guidelines of the University of Wisconsin institutional animal care and use committee.

Cows were fed TMR twice a day (0900 and 1800 h), and amount of feed offered and orts were weighed for each cow daily. Forages samples were collected weekly to adjust for DM. All diet ingredients, TMR, and orts were collected on d 16 to 21 and combined into one sample per period and stored at -20°C for further nutrient analysis. Dry matter contents of all feeds, TMR, and orts were determined by drying at 60°C (forced-air oven) for 48 h. Dried samples were ground to pass a 1-mm screen (Wiley mill; Arthur H. Thomas, Philadel-

Table 3. Fiber components (mean $\pm$ SD) of diets as predicted from in vitro analysis

Item	CS:AS ¹			
	100:0	67:33	33:67	0:100
NDF, % of DM	24.5 $\pm$ 0.4	24.2 $\pm$ 0.3	25.7 $\pm$ 0.3	27.2 $\pm$ 0.3
iNDF, ² % of NDF	27.7 $\pm$ 1.0	29.8 $\pm$ 1.3	32.5 $\pm$ 0.6	33.3 $\pm$ 1.2
Forage NDF, % of DM	19.0 $\pm$ 0.2	19.2 $\pm$ 0.5	19.1 $\pm$ 0.3	19.1 $\pm$ 0.1
Ruminal pdNDF kd, ³ %/h	2.83 $\pm$ 0.4	3.06 $\pm$ 0.4	2.99 $\pm$ 0.4	4.32 $\pm$ 0.4
TTNDFD, ⁴ % of NDF	39.0 $\pm$ 1.4	41.5 $\pm$ 1.8	39.2 $\pm$ 1.9	45.5 $\pm$ 2.4

¹Ratio of corn silage (CS) to alfalfa silage (AS).²iNDF = indigestible NDF determined by in situ incubation for 288 h.³pdNDF = potentially digestible NDF fraction, kd = digestion rate.⁴TTNDFD = predicted total-tract NDF digestibility.

phia, PA) and analyzed for DM, OM (method 942.05; AOAC International, 2006), CP (method 990.03; AOAC International, 2006), ether extract (method 2003.05; AOAC International, 2006), NDF using α -amylase and sodium sulfite (Van Soest et al., 1991), starch (Bach Knudsen, 1997; YSI Biochemistry Analyzer, YSI Inc., Yellow Springs, OH), lignin (method 973.18; AOAC International, 2006), and iNDF (Krizsan and Huhtanen, 2013).

Cows were milked twice daily, and milk yield was recorded at each milking. Milk samples from a.m. and p.m. milkings were collected on d 12 to 15 of each period and analyzed for fat, true protein, lactose, and MUN concentrations by infrared analysis (method 972.16; AOAC International, 2012; AgSource Milk Analysis Laboratory, Menomonie, WI) using a Foss Milko-Scan FT6000 (Foss Electric, Hillerød, Denmark). Average daily yields of fat and protein were calculated from these data for each period. Yield of FCM was calculated according to NRC (2001) equations.

Omasal and Rumen Sampling

Spot samples of omasal digesta leaving the rumen were obtained from the 8 ruminally cannulated cows using the sampling technique described by Huhtanen et al. (1997), Ahvenjärvi et al. (2000) and Reynal and Broderick (2005). The digesta markers used were iNDF (Huhtanen et al., 1994) for the large particle phase (**LP**), lanthanum (La; Kendall et al., 2009) for the small particle phase (**SP**), and CoEDTA (Udén et al., 1980) for the fluid phase (**FP**). Gelatin capsules (44 mL, Tropac Inc., Airfield, NJ) containing 1 g of La and 0.75 g of CoEDTA and approximately 2 g of ground spelt hulls were dosed through the ruminal cannula at 0600, 1200, 1800, and 0000 h (total of 4 g of La and 3 g of CoEDTA per day) from 12 to 18 d with a 3 $\times$ priming dose on d 12. Omasal sampling began approximately 96 h after the first marker dose; samples were then taken 4 times daily at 2-h intervals over 3 consecutive days to represent the 24-h feeding cycle: 0000, 0200, 0400, 0600 (d 16); 0800, 1000, 1200, 1400 (d 17); and 1600, 1800, 2000, and 2200 h (d 18). Before each sampling, it was necessary to confirm the location of the omasal sampling tube, and occasionally, it had to be repositioned in the omasal canal. At each sampling time 200-mL subsamples were pooled and stored at -20°C , over all 3 d to obtain a single 2.4-L composite from each cow in each period for later separation into the 3 omasal phases.

The pooled omasal composites were thawed at room temperature, separated into the 3 omasal phases (LP, SP, and FP) as described by Reynal and Broderick (2005), and stored at -20°C until being freeze-dried

at Anteco Pharma (Lodi, WI). After freeze-drying, LP samples were ground through a 1-mm screen (Wiley mill; Arthur H. Thomas) and SP and FP samples were ground using a coffee grinder, and then all samples were analyzed for markers. Concentration of CoEDTA, La, and iNDF in LP and SP and CoEDTA and La in FP were determined using the methods detailed earlier by Reynal and Broderick (2005) using inductively coupled plasma optical emission spectrometry at a commercial laboratory (Analabs, Fulton, IL) using a Varian Vista-MPX (Agilent Technologies Inc., Santa Clara, CA). Marker concentrations were used to physically recombine DM from the freeze-dried FP, SP, and LP to reconstitute the omasal apparent digesta flowing out of the rumen using the triple-marker method of France and Siddons (1986). Concentrations of CoEDTA, La, and iNDF were distinctly greater in, respectively, the FP, SP, and LP, thus allowing for successful application of the triple-marker method.

Ruminal fluid was collected from the ventral sac of the rumen using a rumen probe at the same time as omasal sampling. A portable pH meter (Accumet AP61, Fisher Scientific, Pittsburgh, PA) was used immediately on the collected ruminal fluid to determine pH. Two 1-mL aliquots of rumen fluid were added to microcentrifuge tubes containing 0.02 mL of 50% H_2SO_4 acid for later VFA analysis. Rumen VFA concentrations were measured by gas liquid chromatography (Supelco, 1998). Concentrations of individual VFA were measured on a Perkin Elmer Clarus 500 (Norwalk, CT) using a 4% Carbowax 20M on 80/120 mesh Carbopack-B-DA, 1.8 mm $\times$ 2 mm column (Supelco Inc., Bellefonte, PA). Two 1-mL aliquots of rumen fluid were also acidified with 0.2 mL of 50% TCA solution and frozen until analysis for ammonia concentration as described by Bal et al. (2000).

Ruminal contents were evacuated manually through the ruminal cannula at 1300 h (4 h after feeding) on d 20 and at 0800 h (1 h before feeding) on d 21 of each period. Body weights were measured immediately after the rumen evacuation. Total ruminal content mass and volume were determined. A 1-kg subsample of ruminal digesta was collected for further nutrient analysis, and evacuated digesta were placed back in the rumen. Ruminal pool sizes (kg) of OM, NDF, iNDF, pdNDF, and starch were determined by multiplying the concentration of each component by the ruminal digesta DM mass (kg). Turnover rate, passage rate from the rumen, and ruminal digestion rate of each component (%/h) were calculated using the following equations:

$$\begin{aligned} \text{ruminal turnover rate (\%/h)} &= 100 \\ &\times [(\text{intake of nutrient/ruminal pool of nutrient})/24]; \end{aligned}$$

ruminal passage rate (%/h) = $100 \times [(\text{omasal nutrient flow} / \text{ruminal pool size of nutrient}) / 24]$; and

ruminal digestion rate (%/h) = ruminal turnover rate (%/h) – ruminal passage rate (%/h).

Apparent total-tract digestibilities of DM, OM, NDF, pdNDF, and starch were determined using iNDF as an internal marker. Six fecal grab samples were collected from each cow at 0000, 0600 (d 16), 0800, 1400 (d 17), 1600, and 2200 h to represent the 24-h feeding cycle. Fecal samples were composited by period and analyzed for DM, OM, NDF, starch, lignin, and iNDF.

Statistical Analysis

Data were analyzed using the mixed procedure of SAS (SAS Institute Inc., 2009) for a replicated 4×4 Latin square design according to the following model:

$$Y_{ijkw} = \mu + L_i + P_j + C_{k(i)} + F_w + FI_{wi} + e_{ijkw}$$

where Y_{ijkw} = dependent variable, μ = overall mean, L_i = fixed effect of square ($i = 1$ to 2), P_j = fixed effect of period ($j = 1$ to 4), $C_{k(i)}$ = random effect of cow k (within square i), F_w = fixed effect of treatment ($w = 1$ to 4), FI_{wi} = interaction between square i and treatment w , and e_{ijkw} = residual error. All reported values are least squares means, which were separated using the PDIFF test with the Tukey adjustment. Linear and quadratic contrasts were tested for treatment effect by replacing CS for AS equally spaced, considering all the fixed and random effects cited above. Significance was declared at $P \leq 0.05$ and trends at $0.05 < P \leq 0.10$.

Predicted (in vitro) compared with in vivo (in cow) parameters used for input and output (Table 9) were analyzed by a similar model by adding a fixed effect of method (1 = in vivo and 2 = in vitro). Random effect was unit, where unit is flask = in vitro and cow = in vivo. Square effect is 1 to 2 for in vivo and 1 for in vitro. Significance was declared at $P \leq 0.05$. All reported values are least squares means, which were separated using the PDIFF test with the Tukey adjustment. Orthogonal contrasts were used to determine main effect of method.

Ruminal pH, VFA, and NH_3 values were analyzed using repeated measures over time:

$$Y_{ijkwm} = \mu + L_i + P_j + C_{k(i)} + F_w + FI_{wi} + e1_{ijkw} + H_m + HFI_{mw} + e2_{ijkwm}$$

where Y_{ijkwm} = dependent variable, μ = overall mean, L_i = fixed effect of square ($i = 1$ to 2), P_j = fixed effect of period ($j = 1$ to 4), $C_{k(i)}$ = random effect of cow k (within square i), F_w = fixed effect of treatment ($w = 1$ to 4), FI_{wi} = interaction between square i and treatment w , and $e1_{ijkw}$ = whole plot error, H_m = effect of hours analyzed as repeated measurements, HFI_{mw} = interaction between hour (m) and treatment (w), and $e2_{ijkwm}$ = is the subplot error. Ruminal data were analyzed with time as repeated measure using the first-order autoregressive variance and covariance structure [AR(1)], which provided the best fit according to Sawa's Bayesian information criterion. Degrees of freedom were calculated using the Kenward-Roger option. Linear and quadratic contrasts were tested for treatment effect by replacing CS for AS equally spaced, considering all the fixed and random effects cited above. The least squares means statement was used to determine treatment means. Significance was declared at $P \leq 0.05$ and trends at $0.05 < P \leq 0.10$.

RESULTS AND DISCUSSION

Forage and Diet Composition

Chemical compositions of forages and soy hulls are shown in Table 1. Crude protein content of CS and AS averaged 6.4 and 21.1%, respectively. Neutral detergent fiber and lignin contents of these forages were typical of high-quality forages. The NDF content was similar for CS and AS, and lignin concentration for AS was higher than CS as was expected (Table 1). Indigestible NDF as a percentage of NDF was 12.0% units higher for AS compared with CS. The CS was predicted to be lower in fiber digestibility with a TTNDFD prediction of 36.0% of total NDF compared with TTNDFD for AS of 42.2% of total NDF (Table 1). Soy hulls were predicted to have a higher fiber digestibility than either CS or AS because of a low fraction of iNDF and a fast rate of digestion of pdNDF.

Ingredient and nutrient composition of experimental diets are shown in Tables 2 and 3. Our goal was to formulate diets with a similar content of NDF but with fiber sources that contained different proportions of pdNDF and rates of digestion of pdNDF. As more alfalfa was included, the ration CP concentration increased and the starch content decreased (Table 2). Supplemental protein and corn grain were adjusted to reduce the differences in CP, starch, and NFC. Soy hulls were also added to the 2 diets with the highest proportions of AS in an attempt to keep diets as similar as possible in NDF but maintain as great a difference in iNDF and rates of digestion of pdNDF as possible. The addition of soy hulls in the 33CS:67AS and 0CS:100AS

Table 4. Effects of varying dietary ratios of corn silage (CS) to alfalfa silage (AS) on feed intake, milk production, milk components, and BW change

Item	CS:AS				SEM	<i>P</i> -value		
	100:0	67:33	33:67	0:100		Diet	Linear	Quadratic
DMI, kg/d	25.2 ^{ab}	25.3 ^a	24.3 ^b	21.9 ^c	0.80	<0.01	<0.01	<0.01
Milk, kg/d	39.8 ^a	37.6 ^b	37.7 ^b	36.4 ^c	0.95	<0.01	0.30	0.01
4% FCM, kg/d	36.2	35.4	35.2	35.6	0.88	0.22	0.29	0.46
Milk composition								
Fat, %	3.57	3.60	3.65	3.64	0.05	0.95	0.92	0.94
Fat, kg/d	1.46	1.38	1.34	1.38	0.03	0.40	0.56	0.58
Protein, %	3.17	3.14	3.12	3.17	0.04	0.24	0.12	0.55
Protein, kg/d	1.25 ^a	1.19 ^b	1.14 ^b	1.16 ^b	0.01	<0.01	0.89	0.02
Lactose, %	4.88 ^a	4.83 ^b	4.92 ^a	4.89 ^a	0.05	<0.01	0.08	0.01
Lactose, kg/d	1.96 ^a	1.84 ^b	1.85 ^b	1.80 ^b	0.04	<0.01	0.19	0.01
MUN, mg/dL	14.6 ^b	14.8 ^b	14.9 ^b	16.1 ^a	0.08	<0.01	0.01	0.01
Cow BW, kg	661.3	652.2	666.4	649.3	9.14	0.08	0.52	0.01
Cow empty BW, kg	565.5	565.3	575.2	566.7	13.4	0.77	0.86	0.54
Cow empty BW change, kg/d	1.23	0.82	0.55	0.33	0.37	0.12	0.17	0.50

^{a-c}Means in the same row with different superscripts differ in diet effect ($P < 0.05$).

diets were equivalent to 0.13 and 0.22 kg of NDF, respectively, which represent only 2.17 and 3.89% of total NDF for the respective diets. The percentage of forage NDF was similar among treatment, averaging 19.1% (Table 3).

In Vitro Fiber-Digestion Prediction

Fiber-digestion kinetic parameters of the forages as predicted by the in vitro assay are summarized in Table 1. The fiber in the CS contains less iNDF than alfalfa, but the rate of digestion of AS is faster than CS fiber, resulting in 6.0 units higher TTNDFD for AS compared with CS. Similar digestion rates for AS were reported by in situ studies; Yang et al. (2001) found a kd of 7.5%/h for AS resulting in NDF digestibility of 49.8%, Coblenz et al. (1997) also found a pdNDF kd of 7.5%/h and NDF digestibility of 53.0% for AS, and Andrighetto et al. (1993) reported a pdNDF kd of 4.64%/h and 41.1% for NDF digestibility for AS hay. The pdNDF kd for AS values reported in the literature are in the range of 3- to 4-units faster than CS pdNDF kd.

The diet containing AS as the only forage source (0CS:100AS) was predicted to be 6% units higher in TTNDFD than the diet with only CS (Table 3). The TTNDFD predictions are indexed to a 630-kg dairy cow that is consuming 23.4 kg/d of DMI. Also, predicted rate of digestion of pdNDF (kd) for the 0CS:100AS diet was faster compared with the 100CS:0AS diet.

DMI, Milk Yield, and Milk Components

Dry matter intake and milk production and composition are shown in Table 4. Dry matter intake was

highest for the diets containing the highest proportions of CS (100:0 and 67:33), and intake decreased as the proportion of CS:AS was decreased to 33:67 and 0:100. (Table 4). Brito and Broderick (2006) observed that cows fed TMR with only AS as the source of forage had greater intake (26.5 kg/d) than cows fed 10% AS and 40% CS (23.7 kg/d). Onetti et al. (2002) also found a higher DMI for cows fed diets with a higher proportion of AS than CS. Arndt (2014) compared diets with different proportions of CS to AS and did not observe differences in DMI among treatment diets. However, when Hassanat et al. (2013) fed diets with 100AS:0CS, 50AS:50CS, and 0AS:100CS, they reported a lower DMI (21.7 kg/d) for the diet with AS as the only forage source. The difference in results among studies when different ratios of CS:AS were fed could be due to different NDF and iNDF concentration among the diets. The in vitro model predicted an increase in diet iNDF concentration by increasing the proportion of AS in the diets, even though the NDF concentration was held approximately constant by adding a combination of soyhulls and alfalfa as sources of more digestible NDF.

The cows fed a diet with AS (0:100) as the only source of forage had lower milk production (36.4 kg/d) compared with the other 3 diets ($P < 0.01$). Cows fed diets with either 67CS:33AS or 33CS:67AS had similar milk yield, which was lower than 100CS:0AS (Table 4). Yield of FCM, however, was similar among treatments. Wattiaux and Karg (2004) fed lactating cows diets that contained 14% AS plus 41% CS or 14% CS plus 41% AS and observed greater milk yield on the diets with the higher proportion of CS (49.0 kg/d) compared with the diet with a high proportion of AS (46.4 kg/d). Similar milk yields were reported in several studies (Onetti et al., 2002; Krause and Combs, 2003; Ruppert

et al., 2003; Arndt, 2014) when different dietary ratios of CS:AS were fed, even though in some of these studies the DMI was different among diets (Onetti et al., 2002; Ruppert et al., 2003). Ruppert et al. (2003) state that despite the difference in composition and digestibility of AS and CS, cows fed diets with different ratios of CS:AS could be expected to produce similar milk yields if the diets are balanced to provide equal energy, metabolizable protein, minerals, and vitamins. It may explain the differences observed in milk yield for this present study, because the energy contents among diets were different.

Milk fat content and milk fat yield were similar among treatment diets (Table 4). Milk fat percentages were higher for cows consuming AS as the only source of forage compared with CS-based diets in previous studies (Broderick, 1985; Onetti et al., 2002; Ruppert et al., 2003). Smith and Harris (1993) reported higher fat content when AS replaced a portion of CS in dairy cows diets, but results of other studies did not detect differences in fat content when cows received diets based on either AS or CS (Broderick, 1985; Charmley et al., 1993). Milk protein content was higher ($P < 0.01$) for cows fed the diet with only CS than for cows fed the other 3 diets (Table 4). Milk lactose content was lowest for diet 67:33; however, lactose yield was highest on the CS-only diet (Table 4). Milk protein percentages were similar among treatment diets; however, milk CP content was greater for cows fed diets with only CS. Milk CP content was greater for cows fed CS-based diets than for cows fed diets based on alfalfa hay or silage (Broderick, 1985; Onetti et al., 2002; Ruppert et al., 2003; Brito et al., 2006). Concentrations of MUN were greater ($P < 0.01$) for the diet with only AS as compared with the other treatments; this was expected because the CP in diets increased as the proportion of

AS added to the diet increased. Wattiaux and Karg (2004) and Brito et al. (2006) observed similar values for MUN for high-AS versus high-CS diets when the levels of CP across diets were similar.

Although, DMI substantially differed, the rumen-empty BW did not differ because of treatment (Table 4). Broderick (1985) in one trial and Santos (2003) did not find differences in BW gain when they compared AS- to CS-based diets; however, in a second trial Broderick (1985) observed a greater BW gain for cows fed with 60% CS compared with cows fed diets with 60% AS or 79% CS. Because we did not observe negative BW changes in cows eating higher proportions of AS, it suggests that cows were not mobilizing body reserves to maintain milk production.

In Vivo Ruminal Fermentation

The mean ruminal pH over the 24-h feeding cycle was higher for diets with high proportions of AS compared with high proportions of CS (Table 5 and Figure 1). The ruminal pH was reduced 4 h after a.m. feeding for diets 100CS:0AS and 67CS:33AS compared with 33CS:67AS and 0CS:100AS diets (Figure 1). At 2 h after p.m. feeding, ruminal pH was lower in cows fed the 100CS:0AS diet, but after 2 h pH was similar among the 4 diets (Figure 1). Even though starch and NFC levels (Table 3) were different among diets, ruminal pH and fat test do not suggest that fiber digestion was impaired. Brito and Broderick (2006) also observed a decrease in pH with diets that had a high proportion of CS compared with diets high in AS, although they reported lower pH than we observed in this study. Krause and Combs (2003) reported that ruminal pH was lower than 5.8 for an extra 1.8 h/d when CS partially replaced AS.

Table 5. Effects of varying dietary ratios of corn silage (CS) to alfalfa silage (AS) on ruminal fermentation in lactating dairy cows

Item	CS:AS				SEM	P-value		
	100:00	67:33	33:67	0:100		Diet	Linear	Quadratic
pH	6.33 ^b	6.39 ^b	6.51 ^a	6.52 ^a	0.05	<0.01	0.37	0.47
Ammonia N, mg/dL	5.69	5.56	5.97	6.97	0.51	0.08	0.04	0.31
Total VFA, mM	85.3	79.1	81.0	81.9	1.77	0.10	0.13	0.24
VFA, % of total VFA								
Acetate (A)	62.9	65.5	66.62	67.7	1.56	0.06	0.54	0.57
Propionate (P)	24.1 ^a	21.0	20.8 ^b	20.2 ^b	0.79	<0.01	0.06	<0.01
Butyrate	9.78	9.90	9.44	9.20	0.38	0.07	0.82	0.35
Isobutyrate	0.57 ^b	0.60 ^b	0.61 ^a	0.62 ^a	0.03	<0.01	<0.01	0.96
2-Methyl butyrate	0.66	0.72	0.60	0.58	0.07	0.06	0.07	0.71
Valerate	1.47	1.77	1.47	1.40	0.25	0.42	0.19	0.52
Isovalerate	0.47	0.60	0.47	0.38	0.03	0.84	0.46	0.41
A:P	2.60 ^b	3.11 ^a	3.20 ^a	3.34 ^a	0.22	<0.01	0.27	0.02

^{a,b}Means in the same row with different superscripts differ in diet effect ($P < 0.05$).

Figure 1. Effects of varying dietary ratios of corn silage (CS) to alfalfa silage (AS) on ruminal pH. Cows were fed at 0800 and 1800 h. A significant time $\times$ diet interaction ($P < 0.05$) was observed, and differences among treatments at each sampling time are indicated in the figure (*) at 1200 and 2000 h. Error bars indicate SE

Ruminal ammonia concentration linearly increased when the dietary proportion of AS increased (Table 5). The values for ruminal ammonia observed in this study are lower than the values reported in other studies for diets with high proportions of AS. Brito and Broderick (2006) reported ruminal ammonia of 10.5 mg/dL for diets with only AS and 6.97 mg/dL for diets with more CS; we observed ruminal ammonia of 6.97 mg/dL for 0CS:100AS and 5.69 mg/dL for 100CS:0AS (Table 5). The total VFA concentration was not affected by diet (Table 5). However, ruminal acetate tended to be lower for diets with higher proportions of CS. The propionate concentration was approximately 4 units higher for 100CS:0AS diet compared with the other treatment diets, which resulted in a decrease in acetate-to-propionate ratio for 100CS:0AS. The increase in propionate for 100CS:0AS can be explained by the higher concentration of starch compared with the other diets (Table 3). Several authors (Hristov and Broderick,

1996; Onetti et al., 2002; Onetti et al., 2004; Brito and Broderick, 2006) also reported reduced ruminal acetate concentration when comparing CS diets with AS diets or when AS was partially replaced by CS.

In Vivo Ruminal Digestion Kinetics and Pool Size

Volume and mass of ruminal digesta did not differ ($P > 0.05$) among treatments (Table 6), even though DMI decreased as the ratio of CS to AS decreased (Table 4). The rumen pool size of DM, OM, NDF, and iNDF did not differ by treatment (Table 6), but the pdNDF pool size decreased as the dietary proportion of CS decreased.

Ruminal turnover rate of DM, OM, and starch were similar among treatment diets (Table 6). Ruminal turnover rate of iNDF did not differ because of treatment, but the turnover rate pdNDF increased linearly as the proportion of AS increased in the diet (Table 6). The

Table 6. Effects of varying dietary ratios of corn silage (CS) to alfalfa silage (AS) on rumen digesta mass and volume, rumen fiber and nutrient pools, and digestion kinetics

Item	CS:AS				SEM	P-value		
	100:0	67:33	33:67	0:100		Diet	Linear	Quadratic
Digesta volume, L	106.1	101.5	106.5	99.5	3.43	0.30	0.64	0.07
Digesta mass, kg	77.0	77.5	80.9	76.5	2.78	0.56	0.50	0.39
Ruminal pool, kg								
DM	10.6	11.3	10.2	10.6	0.46	0.20	0.05	0.80
OM	9.70	10.3	9.77	9.20	0.42	0.17	0.06	0.89
NDF	5.04	5.89	5.64	5.15	0.27	0.10	0.02	0.46
iNDF ¹	2.95	3.22	3.28	3.40	0.17	0.15	0.70	0.13
pdNDF ²	2.09 ^{ab}	2.68 ^a	2.36 ^{ab}	1.75 ^c	0.19	0.02	<0.01	0.94
Starch	0.40 ^b	0.57 ^a	0.37 ^b	0.44 ^b	0.04	0.05	0.11	0.03
Ruminal turnover rate, %/h								
DM	10.1	9.54	8.47	9.94	0.61	0.30	0.29	0.40
OM	10.2	9.64	8.80	10.1	0.62	0.20	0.30	0.52
NDF	5.31	4.59	4.03	4.96	0.27	0.06	0.07	0.70
iNDF	3.30	3.01	2.40	2.70	0.21	0.07	0.97	0.98
pdNDF	8.38 ^a	6.51 ^b	6.65 ^b	10.1 ^a	0.88	0.03	<0.01	0.35
Starch	53.5	43.5	53.4	50.6	7.69	0.75	0.53	0.43
Ruminal digestion rate, %/h								
DM	2.89	3.33	1.97	3.25	0.52	0.33	0.78	0.12
OM	2.04	2.40	1.86	3.14	0.58	0.51	0.37	0.21
NDF	1.84	1.82	1.66	2.21	0.23	0.50	0.25	0.35
pdNDF	3.38 ^b	3.40 ^b	3.41 ^b	7.13 ^a	0.80	0.10	<0.01	0.04
Ruminal passage rate, %/h								
DM	6.99	6.56	6.99	7.23	0.44	0.62	0.24	0.79
OM	8.24 ^a	7.48 ^{ab}	7.40 ^{ab}	6.98 ^b	0.50	0.04	0.70	0.14
NDF	3.55 ^a	2.93 ^b	2.91 ^b	2.74 ^b	0.22	0.01	0.87	0.02
pdNDF	4.70 ^a	3.11 ^b	3.24 ^b	2.98 ^b	0.33	0.01	0.48	0.01
iNDF	2.71	2.78	2.87	2.71	0.24	0.90	0.64	0.74

^{a-c}Means in the same row with different superscripts differ in diet effect ($P < 0.05$).

¹iNDF = indigestible NDF fraction.

²pdNDF = potentially digestible NDF fraction.

ruminal digestion rate (Table 6) of DM, OM, and NDF were similar among treatments, with overall means of 2.86, 2.36, and 1.88%/h, respectively, for 100CS:0AS, 67CS:33AS, 33CS:67AS, and 0CS:100AS. The rate of pdNDF digestion also increased as the proportion of AS increased, a 3.75-unit increase in pdNDF kd for the diet with AS as the sole forage source compared with the diet with only CS as forage source. Although, the opposite was observed for rate of passage of pdNDF, kp was higher for 100CS:0AS compared with 0CS:100AS, a similar effect was observed for NDF kp (Table 6). Voelker Linton and Allen (2008) reported similar pdNDF kd (7.5%/h) and iNDF kp (2.9%/h) for a diet with AS as only forage source. They also reported a similar intake of DM (20.9 kg/d) and NDF (5.6 kg/d); however, iNDF intake (4.7 kg/d) was higher than we observed in this trial. The increase in DMI for cows fed diets with increasing proportions of CS could have increased passage of pdNDF and consequently decreased the extent of ruminal fiber degradation. The diets with higher proportions of AS silage had higher degradation rates for pdNDF as was predicted by in vitro digestion rates (Table 2). No difference was observed for iNDF kp

among treatments, averaging 2.77%/h. A similar value was observed by Krizsan et al. (2010), where the iNDF kp ranged from 2.66 to 2.87%/h across a diverse set of forages.

Nutrient Digestibility

Digestibility of DM, OM, and starch were greater for the diet containing only CS when compared with the diet with only AS. A quadratic effect was observed when different ratios of CS to AS were fed (Table 7). Apparent total-tract digestibility of DM and OM did not differ when different ratios of CS to AS were fed (Krause and Combs, 2003; Ruppert et al., 2003; Arndt, 2014). However, DM digestibility was significantly higher for diets containing forage from CS versus AS in other trials (Broderick, 1985; Hristov and Broderick, 1996), whereas Santos (2003) found the opposite effect. Apparent total-tract digestion of starch was greater for diets with high proportion of CS because of a high concentration of starch in the diets.

Total NDF and pdNDF intake was lower for cows fed a high proportion of AS compared with diets

Table 7. Effects of varying dietary ratios of corn silage (CS) to alfalfa silage (AS) on digestion of DM, OM, and starch

Item	CS:AS				SEM	P-value		
	100:0	67:33	33:67	0:100		Diet	Linear	Quadratic
DM								
Intake, kg/d	25.1 ^{ab}	25.3 ^a	24.3 ^b	21.9 ^c	0.80	0.01	<0.01	<0.01
Apparent total-tract digestion, %	71.4 ^a	69.4 ^{ab}	70.6 ^a	67.2 ^b	0.87	0.02	0.14	0.06
OM								
Intake, kg/d	23.8 ^a	23.7 ^a	22.5 ^b	19.9 ^c	0.73	<0.01	<0.01	<0.01
Apparent total-tract digestion, %	73.2 ^a	70.9 ^a	71.9 ^a	68.5 ^b	0.09	0.01	0.14	<0.01
Starch								
Intake, kg/d	6.35 ^a	5.90 ^b	4.63 ^c	3.91 ^d	0.16	<0.01	<0.01	<0.01
Apparent total-tract digestion, %	98.0 ^a	96.6 ^{ab}	95.6 ^b	94.1 ^b	0.79	0.01	0.07	0.02

^{a-d}Means in the same row with different superscripts differ in diet effect ($P < 0.05$).

with a high proportion of CS, which could be a consequence of lower DMI for diets with higher proportions of AS, whereas the iNDF intake was lower for the 100CS:0AS diet (Table 8). The apparent ruminal digestion of NDF and pdNDF was greater ($P < 0.01$) for 0CS:100AS compared with the 100CS:0AS diet. The NDF and pdNDF digestibilities were 9.4 and 21.5 units higher, respectively, with AS as the sole dietary forage compared with the diet with only CS as the source of forage. The apparent ruminal digestibility of fiber was similar among the 3 diets that contained alfalfa, but ruminal digestibility of pdNDF increased as the proportion of alfalfa increased. Consequently, there was a reduction in NDF and pdNDF flux from the rumen with increasing proportions of AS in the diets, resulting in a greater ($P < 0.01$) total-tract NDF digestibility for 0CS:100AS compared with 100CS:0AS. Dado and Allen (1995) observed similar values for NDF digestibility (43.5%) when high-quality AS was fed to dairy cows. Arndt (2014) also reported a linear increase in digestibility of NDF (12.6 percentage units) as AS ratio in the diet increased and CS decreased. The pdNDF

digestibility in the total tract was significantly higher for 0CS:100AS compared with the other treatment diets. The higher digestibility of NDF and pdNDF for 0CS:100AS could be explained by the faster digestion rates of this diet compared with the other treatment diets (Table 6). In addition, the decrease in DMI by adding more AS in the diet resulted in a decrease in passage rate, which could also increase the time that the fiber fractions are retained in the rumen, resulting in an increase in digestibility. Brito et al. (2006) did not observe differences in rumen NDF digestibility when AS was fed alone or with different proportion of CS; however, they found an increase in total-tract NDF digestibility for diets with a high proportion of AS. Ruppert et al. (2003) also observed that the total-tract NDF digestibility of AS-based diets was approximately 10 units higher compared with CS-based diets (46.2 vs. 36.7% of NDF digestibility). High-quality alfalfa and high-quality CS that contain similar NDF concentration appear to digest much differently because of differences in pools of pdNDF and differences in the rates of digestion of pdNDF.

Table 8. Effects of varying dietary ratios of corn silage (CS) to alfalfa silage (AS) on digestion of NDF

Item	CS:AS				SEM	P-value		
	100:0	67:33	33:67	0:100		Diet	Linear	Quadratic
NDF								
Intake, kg/d	6.24 ^{ab}	6.44 ^a	6.01 ^b	5.58 ^c	0.20	<0.01	<0.01	0.18
Apparent ruminal digestion, %	31.3 ^b	36.6 ^a	36.9 ^a	40.7 ^a	1.73	<0.01	0.38	0.02
Passage to omasum, kg/d	4.31 ^a	4.11 ^a	3.80 ^{ab}	3.30 ^b	0.22	<0.01	0.02	0.04
Apparent total-tract digestion, %	38.2 ^b	40.9 ^{ab}	39.4 ^{ab}	43.8 ^a	1.48	<0.01	0.28	0.03
Potentially digestible NDF								
Intake, kg/d	4.28 ^a	4.24 ^a	3.74 ^b	3.36 ^c	0.13	<0.01	<0.01	<0.01
Apparent ruminal digestion, %	43.9 ^c	53.5 ^b	57.4 ^b	65.4 ^a	2.62	<0.01	0.07	<0.01
Passage to omasum, kg/d	2.40 ^a	1.99 ^b	1.59 ^c	1.15 ^d	0.13	<0.01	<0.01	<0.01
Apparent total-tract digestion, %	53.6 ^b	58.9 ^b	60.5 ^b	71.2 ^a	2.79	0.03	0.02	<0.01
iNDF ¹ intake, kg/d	1.96 ^b	2.20 ^a	2.27 ^a	2.23 ^a	0.07	<0.01	0.09	<0.01

^{a-d}Means in the same row with different superscripts differ in diet ($P < 0.05$).

¹iNDF = indigestible NDF fraction.

Table 9. Comparison of rumen and total-tract NDF digestion of diets predicted from TTNDFD model and observed in vivo¹

Item	Method		SEM	<i>P</i> -value, method ²
	Predicted	In vivo		
Input				
pdNDF, kg/d	3.81	3.90	0.15	0.60
pdNDF kd, %/h	3.86	4.40	0.54	0.40
pdNDF kp, %/h	2.67	3.51	0.28	<0.01
Output				
NDF digested in rumen, kg	2.25	2.19	0.07	0.64
NDF digested in hindgut, kg	0.15	0.27	0.11	0.37
NDF digested in total tract, kg	2.40	2.46	0.12	0.69
TTNDFD, % of total NDF	41.8	40.6	1.86	0.51

¹TTNDFD = total-tract NDF digestibility; pdNDF = potential digestible NDF fraction; kd = digestion rate; kp = passage rate.

²Method = comparison between in vitro and in vivo values.

In Vitro Versus In Vivo

The input variables (pdNDF intake, kd, iNDF, and kp) and outputs (ruminal, hindgut, and total-tract NDF digestion) predicted from the in vitro model were compared with what was observed in vivo (Table 9). The pdNDF intake predicted from the in vitro model was similar to pdNDF intake observed in vivo. In addition, no differences were observed for pdNDF kd between methods. However, a difference ($P < 0.01$) was observed for pdNDF kp between methods. The fixed value of 2.67%/h used for pdNDF kp in the TTNDFD model assumes the DMI of 23.4 kg/d for a high-producing dairy. The passage rate of pdNDF observed in vivo was faster than predicted by the regression of Krizsan et al. (2010).

Predicted rumen pdNDF kd and TTNDFD summarized by treatment diets for the in vitro method are presented in Table 3, and for the in vivo method in Tables 6 and 8. The in vitro method predicted TTNDFD of 39.0, 41.5, 39.2, and 45.5% of NDF for 100CS:0AS, 67CS:33AS, 33CS:67AS, and 0CS:100AS, respectively (Table 3), whereas in in vivo measurements TTNDFD average 38.2, 40.9, 39.4, and 43.8% of NDF for 100CS:0AS, 67CS:33AS, 33CS:67AS, and 0CS:100AS, respectively (Table 8). The in vitro TTNDFD test predicted total-tract NDF digestibility of treatment diets similar ($P = 0.51$) to digestibility observed in vivo (Table 9).

The amount of NDF digested at rumen and hindgut was similar ($P = 0.64$ and 0.37 , respectively) when the in vitro and in vivo observations were compared (Table 9). The TTNDFD model assumes that 10% of NDF digestion occurs in the hindgut in a high-producing dairy cow eating ad libitum. This was similar to what was observed in vivo. The Cornell Net Carbohydrate and Protein System (CNCPS) model (Fox et al., 2004;

Tylutki et al., 2008) assumes that 20% of potentially digestible NDF entering the small intestine is digested.

Colombini et al. (2012) compared total-tract NDF digestion measured from fecal collection to total-tract NDF digestion predicted from an in vitro assay according to CNCPS model and reported that the in vitro prediction values (37.8%) for CS diets were lower than in vivo measurements (51.5%) using the same diets. The authors suggested that the underestimation of NDF digestion by the in vitro assay in the CNCPS model could be explained by an overestimation of the passage rate of fiber. Krizsan et al. (2010) also indicates that fiber passage estimates derived from rumen evacuation data are lower than those predicted from the CNCPS model. The CNCPS model uses a regression that predicts passage of labeled feed particles from the rumen, and it assumes that particle passage rates are similar to NDF passage rate. The passages of feed particles, which consist of several nonfiber components such as protein, and starch are likely different than passage of iNDF or pdNDF.

CONCLUSIONS

The NDF digestibility coefficients predicted by the in vitro TTNDFD method were similar to the in vivo values. The fiber digestibility coefficients suggest that the faster rate of digestion of alfalfa fiber compensated for its lower potentially digestible fraction compared with CS. However, as the proportion of AS increased, the amount of indigestible NDF in the rumen increased, and it could be a predominant factor in limiting feed intake. The in vitro estimates of pdNDF intake and rate of digestion of pdNDF were similar to what was observed in vivo and when applied to a relatively simple model, were a good predictor of in vivo fiber digestion. The in vitro TTNDFD method could be a useful tool

for evaluating forage quality and fiber digestibility for lactating dairy cows.

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