J. Dairy Sci. 84:204–212

Effects of Forage Neutral Detergent Fiber and Yeast Culture on Performance of Cows During Early Lactation[1]

Z. Wang, M. L. Eastridge, and X. Qiu
Department of Animal Sciences
The Ohio State University, Columbus 43210

ABSTRACT

Sixty Holstein cows were assigned to two treatments at 21 d before calving and were group-fed a prepartum diet with or without yeast culture. After parturition, cows were individually fed one of five treatments for 140 d: 1) 21% forage neutral detergent fiber (NDF) without yeast culture, 2) 21% forage NDF with yeast culture, 3) 17% forage NDF without yeast culture, 4) 17% forage NDF with yeast culture, and 5) 25% forage NDF with yeast culture for 30 d and then switched to diet 4 for 110 d. Cows fed yeast culture prepartum were also fed yeast culture postpartum (60 g/d). A quadratic increase to 25, 21, and 17% forage NDF occurred during the first 30 d in milk (DIM) for dry matter intake, milk yield, and milk protein yield. No differences were observed for yeast culture or interaction of yeast culture and forage NDF for the first 30 DIM. Feeding 17 versus 21% forage NDF increased milk protein percentage and tended to increase dry matter intake as a percentage of body weight from 31 to 140 DIM. During this period, yeast culture tended to increase milk fat percentage and appeared to have positive effects on dry matter intake, milk yield, and milk fat yield when supplemented to diets with 21% forage NDF but not with 17% forage NDF. Feeding 17% forage NDF may be too low for the first 30 DIM but may improve animal performance after 30 DIM compared to 21% forage NDF.
(**Key words:** forage neutral detergent fiber, yeast culture, early lactation)

Abbreviation key: **ECM** = energy-corrected milk, **FNDF** = forage NDF, **NFC** = nonfiber carbohydrates, **NFFS** = nonforage fiber source, **PEE** = partial energy efficiency for milk, **YC** = yeast culture.

INTRODUCTION

The provision of forage fiber in the diet is an important factor for optimizing milk production and maintaining ruminal health. The NRC (1989) recommends a minimum of 28% NDF in the total dietary DM, of which at least 75% should be supplied by forage. This recommendation suffices for traditional forage and concentrate combinations but may not be appropriate when substantial amounts of nonforage fiber sources (**NFFS**) are fed. Sarwar et al. (1992) replaced forage NDF (**FNDF**) with NDF from soybean hulls and found that 18.6% FNDF was adequate for ruminal function and milk production when the total diet contained 31% NDF. Zhu et al. (1997) lowered FNDF to 17% for Holstein dairy cows when 31% total NDF was partially supplied with corn gluten feed, wheat middlings, or a blend of distillers dried grains and hominy. Other studies have reduced FNDF concentration to 16% in diets with 30 to 35% total NDF fed to Jersey (Harmison et al., 1997) and Holstein (Slater et al., 2000) cows.

Although several studies to investigate dietary NDF concentration have been conducted with early lactation cows, the start of the experiments has not been consistent across the trials, and most of the research has been conducted with cows past peak lactation. Therefore, information on FNDF concentration for cows between parturition and peak lactation is limited. Slater et al. (2000) reported that FNDF could be reduced from 16 to 9% in the diet for cows beyond 60 DIM; however, a low FNDF diet fed to cows at calving may lead to a greater incidence of metabolic disease (Grant, 1997).

Yeast cultures (**YC**) have been fed to dairy cows with varied responses. Improvements in DMI and milk yield (Erasmus et al., 1992; Putnam et al., 1997; Robinson and Garrett, 1999; Wohlt et al., 1991), NDF digestibility (Carro et al., 1992; Plata et al., 1994; Robinson, 1997; Wohlt et al., 1991), and milk fat yield (Putnam et al., 1997) have been reported, but in other studies (Arambel and Kent, 1990; Swartz et al., 1994), no beneficial responses were found. Wohlt et al. (1991) suggested that supplementing YC prior to parturition and extending through the period of peak lactation was necessary to evaluate the effect of YC on lactating cows. Robinson

Received May 25, 2000.
Accepted August 30, 2000.
Corresponding author: M. L. Eastridge; e-mail: eastridge.1@osu.edu.
[1]Salaries and research support provided by State and Federal funds appropriated to the Ohio Agricultural Research and Development Center, The Ohio State University.

(1997) repeated this method in a shorter period and found that YC lessened the body condition loss during the 2 wk prepartum. The objective of this research was to determine the effects of altering the concentration of FNDF and supplementing diets with YC on the performance of dairy cows during early lactation.

MATERIALS AND METHODS

Experimental Procedures

Fifty dry cows and 10 heifers were assigned to two treatments at 21 d before calving. Thirty-six of the dry cows and heifers were fed a transition diet with 60 g of YC/d (Diamond V XP; Diamond V Mills, Cedar Rapids, IA), and 24 were fed a diet without YC. At parturition, cows were blocked based on parity, projected milk yield (previous lactation 305-d mature equivalent and genetic merit for dry cows and heifers, respectively), and calving date. Cows in each block received one of five treatments for 140 d: 1) 21% FNDF without YC, 2) 21% FNDF with YC, 3) 17% FNDF without YC, 4) 17% FNDF with YC, and 5) 25% FNDF with YC for 30 d then switched to diet 4 for an additional 110 d. Cows fed YC prepartum received the same amount of YC postpartum.

Cows and Diets

Dry cows and heifers were group fed, but after calving, the animals were moved into a tie-stall barn and fed individually. Any cows with serious diseases or those that did not receive sufficient time on prepartum treatments (less than 2 wk) were replaced with animals of similar parity and projected 305-d milk yield. The ingredient composition of diets is in Table 1. The FNDF was provided by corn silage and alfalfa silage in a ratio of 60:40 (DM basis) after parturition. The amounts of corn and alfalfa silages fed were based on providing the expected FNDF concentration in the diets. Soybean hulls were supplied to maintain total dietary NDF and dilute NSC concentration of diets. Prepartum and postpartum diets were mixed once daily and fed as a TMR. The dry cows and heifers were fed once daily at 0730 h. Lactating cows were fed twice daily at 0630 and 1800 h. All cows were injected with bST (Posilac; Monsanto, St. Louis, MO) beginning at 70 DIM and continuing at 14-d intervals throughout the experiment.

Feed and Milk Sample Collection

Throughout the experiment, animals were fed at 110% of expected feed intake. The amounts of feed offered and refused were weighed daily. The corn and alfalfa silages were sampled weekly, and concentrates were sampled biweekly. Samples of these feeds were oven-dried at 60°C to determine DM, and additional samples were stored in a refrigerator for laboratory analyses. The diets were adjusted weekly based on the DM contents of forages and concentrates. Cows were milked twice daily at 0530 and 1600 h. Milk samples were taken weekly from four consecutive milkings and analyzed for milk fat and milk protein by infrared spectroscopy (DHI Cooperative, Inc., Powell, OH).

Laboratory Analyses

Forages, concentrates, and TMR samples were collected weekly and composited monthly. Samples were dried in a forced-air oven at 60°C and then ground through a 2-mm screen in a Wiley mill (Arthur H. Thomas Co., Philadelphia, PA). The ground samples were analyzed for DM, ash, and N according to methods of the AOAC (1990). Neutral detergent fiber, ADF, and lignin for forages and TMR were determined sequentially according to Van Soest et al. (1991). Samples for fiber analyses were first rinsed with 50 ml of hot ethanol to remove the fat from the residues, followed by soaking in 30 ml of 8 M urea solution and 0.2 ml of α-amylase (Sigma A-5426; Sigma Chemical Co., St Louis, MO) for a minimum of 4 h or overnight before the NDF solution was added. Samples of forages and TMR were analyzed for neutral detergent insoluble N and ADIN. The TMR samples were analyzed for minerals by inductively coupled plasma spectrometry at the Research Extension Analytical Laboratory (Wooster, OH). Total fatty acid concentration of feed samples was determined according to the procedure described by Sukhija and Palmquist (1988). To determine NSC by the procedure described by Sarwar et al. (1992), we further ground samples through a 1-mm screen. Glucose was used to obtain a standard curve for each run, and cornstarch was incubated with samples to minimize the batch effect and to correct standard curves. The NSC concentration was calculated based on the concentration of glucose produced during the incubation and the relationship of glucose concentration and amount of starch in the same batch of samples. The nonfiber carbohydrates (**NFC**) were calculated by difference using the following equation:

$$NFC = 100 - NDF_{N\text{-free}} - CP - ash - (fatty\ acids / 0.9).$$

Body Weight and Energy Measures

After calving, cows were weighed once weekly after the a.m. milking. Body condition scores were recorded at 21 d before parturition, at parturition, and at 28, 56, 84, 112, and 140 DIM using the 1 (thin) to 5 (fat) scale

Table 1. Ingredient composition of diets fed to cows before and after parturition.

	Prepartum 25% FNDF		Postpartum 17% FNDF		Postpartum 21% FNDF		Postpartum 25% FNDF[1]
Ingredient	No YC	YC[2]	No YC	YC	No YC	YC	YC
	(% of DM)						
Corn silage	34.9	34.9	23.4	23.3	29.1	29.1	34.5
Alfalfa silage	23.0	23.0	15.6	15.6	19.1	19.1	22.9
Dry shelled corn	17.8	17.1	17.8	17.6	25.0	24.8	19.4
Soybean hulls	14.37	14.37	20.83	20.83	2.81	2.81	. . .
Soybean meal, 44% CP	8.88	8.88	13.56	13.56	17.15	17.15	14.24
Corn gluten meal	. . .	. . .	2.25	2.25	0.29	0.29	2.25
Blood meal	. . .	. . .	1.92	1.92	1.92	1.92	1.91
Tallow	. . .	. . .	2.04	2.04	2.04	2.04	2.04
Limestone	0.25	0.25	1.06	1.06	1.13	1.13	1.02
Dicalcium phosphate	. . .	. . .	0.65	0.65	0.56	0.56	0.56
Magnesium oxide	. . .	. . .	0.13	0.13	0.13	0.13	0.12
Potassium sulfate	. . .	. . .	0.13	0.13	0.13	0.13	0.12
Vitamin A[3]	0.05	0.05	0.02	0.02	0.02	0.02	0.02
Vitamin D[4]	0.05	0.05	0.02	0.02	0.02	0.02	0.02
Vitamin E[5]	0.25	0.25	0.06	0.06	0.06	0.06	0.06
Salt[6]	0.50	0.50	0.52	0.52	0.52	0.52	0.52
Yeast culture[7]	. . .	0.65	. . .	0.27	. . .	0.27	0.27

[1]25% forage NDF (FNDF) fed for 30 d and then cows were switched to 17% FNDF with YC for 110 d.
[2]YC = Yeast culture.
[3]Contained 30,000 IU of vitamin A/g.
[4]Contained 3000 IU of vitamin D/g.
[5]Contained 44 IU of vitamin E/g.
[6]Contained 94% salt, 0.75% Zn, 0.6% Mn, 0.5% Fe, 0.25% Cu, 0.01% I, 500 mg/kg of Co, and 600 mg/kg of Se.
[7]Provided by Diamond V Mills, Cedar Rapids, IA.

(Edmonson et al., 1989). The NE_L concentration of the diets was estimated (Weiss, 1998). Energy-corrected milk (**ECM**) was based on the equation developed by Tyrrell and Reid (1965). The factors in the equation were modified to use 3.5% milk fat and 3.2% milk protein. Measures of energy utilization were calculated with coefficients from NRC (1989).

Statistical Analyses

The entire experiment was separated into the dry and lactation (0 to 140 DIM) periods. The lactation period was further divided into the first 30 DIM and a period from 31 to 140 DIM. For the dry period, no statistical analyses were conducted because animals were group fed. The MIXED model procedure of SAS (1997) with repeated measures for week of lactation was used. The blocks and cows were regarded as random factors in the mixed model. The first-order autoregressive (AR(1)) type was selected as the appropriate covariance structure for the repeated measures. The main effects of FNDF and YC and the interaction of FNDF and YC on DMI, BW, BW change, milk yield and composition, and energetic efficiency were evaluated using orthogonal contrasts. For the first 30 DIM, the effects of YC and the interaction between YC and FNDF were examined with treatments 1 and 3 against treatments 2 and 4, and the linear and quadratic effects of FNDF were evaluated with treatments 2, 4, and 5. For the period from 31 to 140 DIM, the contrasts were made on treatments 1, 2, 3, and 4 to analyze effects of FNDF, YC, and the interaction of YC and FNDF and on treatments 2 and 5 to measure the effect of feeding 17 or 25% FNDF with YC during the first 30 DIM on subsequent animal performance and feed efficiency. There were no interactions of treatment × week of lactation during the first 30 DIM; some interactions were found after 30 DIM. The BCS was analyzed for the whole experimental period (0 to 140 DIM) with the prepartum BCS as a covariate, using the MIXED model procedure of SAS (1997). Significance was declared at $P < 0.05$, and a tendency toward significance was set as $P < 0.10$.

RESULTS AND DISCUSSION

As expected, the chemical compositions of diets with or without YC fed prepartum (Table 2) were similar. These two diets contained 38.7% NDF, 39.3% NFC, 25.0% FNDF, and 15.5% CP. The actual NDF concentration was two units higher and CP was one unit

Table 2. Chemical composition of diets fed to cows before and after parturition.

	Prepartum 25% FNDF		Postpartum 17% FNDF		Postpartum 21% FNDF		Postpartum 25% FNDF[1]
Item[2]	No YC	YC[3]	No YC	YC	No YC	YC	YC
DM, %	50.3	50.1	57.0	57.8	53.0	53.5	51.1
	(% of DM)						
CP	15.5	15.4	18.9	19.0	18.7	19.3	18.9
NDF	38.9	38.4	35.4	34.8	30.5	29.2	30.8
$NDF_{N\text{-free}}$	36.7	36.2	33.0	32.5	28.5	27.2	28.6
FNDF	24.8	25.1	16.8	17.0	21.1	21.1	25.0
ADF	26.5	25.4	23.4	23.3	19.1	18.1	19.2
ADL	3.45	3.41	2.61	2.65	2.75	2.51	2.84
NDIN	0.34	0.35	0.38	0.38	0.31	0.31	0.34
ADIN	0.15	0.16	0.18	0.17	0.17	0.17	0.18
Fatty acids	2.42	2.50	3.91	3.92	4.18	4.26	4.16
NSC	32.0	33.6	30.9	30.7	37.5	38.2	34.8
NFC	38.9	39.7	37.4	37.8	41.7	42.2	41.3
NE_L,[4] Mcal/kg	1.62	1.63	1.74	1.75	1.78	1.80	1.77
Ash	6.19	5.95	6.42	6.39	6.38	6.57	6.54
P	0.32	0.34	0.47	0.48	0.51	0.48	0.46
K	1.90	1.84	1.59	1.53	1.61	1.59	1.64
Ca	0.97	0.96	1.16	1.32	1.27	1.11	1.21
Mg	0.25	0.25	0.35	0.28	0.30	0.36	0.27

[1]25% forage NDF (FNDF) diet only fed for the first 30 DIM.

[2]ADL = Acid detergent lignin; $NDF_{N\text{-free}}$ = NDF adjusted for CP (N × 6.25) contamination; NDIN = Neutral detergent insoluble N; NFC = nonfiber carbohydrates, calculated by difference; and NSC were enzymatically analyzed.

[3]YC = Yeast culture.

[4]Calculated using the equation described by Weiss (1998).

higher than expected. The chemical composition of diets fed postpartum is in Table 2. The actual FNDF levels in the diets were similar to the expected levels for the five treatments. Diets with 17, 21, and 25% FNDF contained 35.1, 29.8, and 30.8% NDF and 37.6, 42.0, and 41.3% NFC, respectively. The NSC concentrations in the diets were 4 to 7 units lower than the NFC values. This is to be expected because NFC includes pectin and organic acids that are not included in the enzymatic analysis. Diets contained 18.7 to 19.3% CP, which was slightly higher than expected (18.6% of DM). The expected RDP for the diets was 60.4% of CP (based on tabular values). The NDF level in the diet with 25% FNDF was similar to the diet with 21% FNDF and was about 5 percentage units lower than those in the diets with 17% FNDF because 20.8% soybean hulls replaced corn and forages in the diets with 17% FNDF. The highest concentration of NSC in the diet was with 21% FNDF, primarily because of higher proportions of corn and soybean meal. The high concentration of soybean hulls in the diet with 17% FNDF resulted in the lowest NSC concentration. The ratio of FNDF:NSC was 0.55 for 17 and 21% FNDF diets and 0.72 for the diet with 25% FNDF. Mineral concentrations met or exceeded NRC (1989) recommendations. The calcium concentration was higher than expected, partially because of underestimated calcium concentration in alfalfa silage.

The chemical compositions of corn and alfalfa silages are in Table 3. The NDF concentrations were similar (43.4% of DM) between the forages, but NFC (27.2 vs. 42.5% of DM) and NSC (5.1 vs. 38.8% of DM) were lower, as expected, in alfalfa silage. The greater difference between NFC and NSC for alfalfa (22.1) than corn silage (3.7) was primarily due to higher concentrations of pectin and organic acids in alfalfa silage (Van Soest et al., 1991).

Table 3. Chemical composition of forages.

Item[1]	Corn silage	Alfalfa silage
DM, %	33.7	46.0
	(% of DM)	
CP	8.0	20.5
NDF	43.3	43.4
$NDF_{N\text{-free}}$	42.4	40.2
ADF	25.6	34.3
ADL	2.67	7.68
NSC	38.8	5.1
NFC	42.5	27.2
Ash	4.30	9.90

[1]ADL = Acid detergent lignin; $NDF_{N\text{-free}}$ = NDF adjusted for CP (N × 6.25) contamination; NFC = nonfiber carbohydrates, calculated by difference; and NSC were enzymatically analyzed.

Feed Intake Before Calving

The average DMI (14.6 vs. 13.9 kg/d), FNDF intake (3.43 vs. 3.22 kg/d), and NE_L intake (25.4 vs. 23.9 Mcal/d) were numerically higher for cows fed the diet with YC than those not fed YC, respectively (data not in tables and not statistically analyzed). The effect of YC on prepartum DMI has been investigated in several studies. Most commonly, YC increased the viable count of bacteria in ruminal fluid, especially the cellulolytic bacteria (Wallace and Newbold, 1993) and lactate-utilizing bacteria (Nisbet and Martin, 1991). Wallace (1994) proposed that YC increased the rate of cellulolysis and the flow of microbial protein, which resulted in increased DMI, but the effects of YC on ruminal fermentation and animal performance have been variable. Robinson (1997) did not find any improvement in DMI prepartum when YC was fed to cows from 14 d prepartum to calving. Similar results were reported by Robinson and Garrett (1999) and Soder and Holden (1999), but the FNDF levels were between 38.2 to 55.5% of dietary DM, which were higher than that in our trial (25% FNDF). Diets with high forage concentrations may limit the effect of YC on animal performance (Williams and Newbold, 1990; Wohlt et al., 1991, 1998). The physical limitation to DMI caused by high FNDF in the diets (Ruiz et al., 1995) may overcome the effect of YC on DMI (Carro et al., 1992).

The prepartum FNDF level (25% of DM) was lower than that in several other studies (Robinson and Garrett, 1999; Soder and Holden, 1999; Wohlt et al., 1998). Minor et al. (1998) found that low FNDF (25.2% of DM) with high NFC (43.8%) resulted in higher DMI prepartum than high FNDF (46.0% of DM) with low NFC (23.5%). No metabolic disease was observed in their study, demonstrating the possibility to reduce FNDF concentration in the diet fed prepartum.

Feed Intake After Calving

The DMI during the experimental period is in Figure 1. A quadratic effect of 17, 21, and 25% FNDF occurred in diets containing YC for intakes of DM (18.5, 21.3, and 18.7 kg/d, respectively), NE_L (32.4, 38.4, and 33.1 Mcal/d, respectively), NSC (5.68, 8.14, and 6.51 kg/d, respectively), and CP (3.50, 4.13, and 3.56 kg/d, respectively) during the first 30 DIM, but no effect on NDF intake was found (Table 4). As expected, there was a linear effect of dietary FNDF on FNDF intake. Because the previous data (Harmison et al., 1997; Sarwar et al., 1992; Slater et al., 2000; Zhu et al., 1997) were usually obtained for cows past peak lactation, comparisons to the current study are difficult to evaluate. However, the results may be explained by the adaptation process of ruminal fermentation. Dairy cows adapt to the

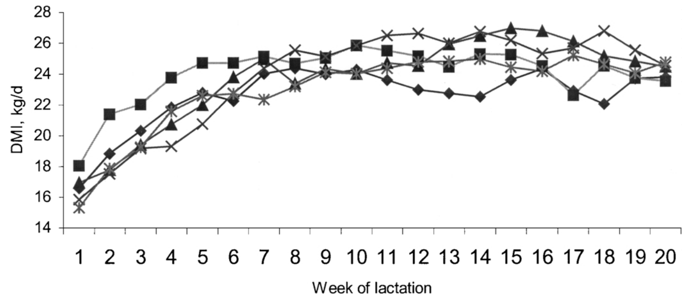

Figure 1. The DMI for cows fed 21% forage NDF (FNDF) without yeast culture (YC) (◆), 21% FNDF with YC (■), 17% FNDF without YC (✖), 17% FNDF with YC (✳), and 25% FNDF with YC for the first 30 DIM and 17% FNDF with YC for 31 to 140 DIM (▲)(SEM = 1.1).

change of dietary composition by altering microbial population and ruminal papillae development to tolerate high acid production, but complete adaptation of ruminal flora to a high starch diet requires 3 to 4 wk (Huntington et al., 1981) and the development of the ruminal papillae may take 4 to 6 wk (Dirksen et al., 1985). In the current study, the high concentrate diets were fed for 3 wk before the projected calving date, which is less than the recommended time for ruminal papillae development. Adequate FNDF also should be provided to stimulate saliva secretion and increase buffering capacity. The difference between FNDF in the diet fed prepartum and FNDF fed after parturition should be considered as well. In the study by Minor et al. (1998), a decrease of dietary FNDF from 25.2% prepartum to 17.4% postpartum decreased concentrations of plasma NEFA and BHBA and increased the liver glycogen:triglyceride ratio to a greater extent than a decrease of dietary FNDF from 46.0 to 20.0% of DM. The sharpness of the decline in FNDF concentration may be more important than the actual concentration of FNDF when the effective fiber in the diet is adequate. The diets fed after parturition in the study by Minor et al. (1998) contained 8% whole cottonseed. Clark and Armentano (1993) found that whole cottonseed had a similar ability to maintain milk fat percentage as alfalfa silage, but soybean hulls only had one half the effectiveness of forages (Swain and Armentano, 1994). Therefore, 21% FNDF may have been necessary to mediate the reduction from 25% FNDF prepartum compared to 17% FNDF postpartum when soybean hulls were used as the primary NFFS in this trial.

There was no interaction of FNDF concentration and YC on DMI. The DMI during the first 30 DIM for cows fed diets with YC was numerically, but not statistically, higher (19.9 vs. 18.8 kg/d) compared with that without YC. The YC supplementation tended to increase CP intake (3.82 vs. 3.54 kg/d), probably because of the numerically higher DMI and the slightly higher CP percentage in the diets with YC.

After 30 DIM (Table 5), the interaction between intakes of FNDF, NDF, and NSC and weeks of lactation were significant, primarily because cows fed the diets with 17% FNDF lagged behind in DMI until about 8 wk of lactation compared with cows fed 21% FNDF diets. These changes in DMI, in conjunction with the 17% FNDF diets being higher in NDF and lower in FNDF and NSC, resulted in the interaction of treatment with time. The diet with 25% FNDF was 5 percentage units lower in NDF and 5 percentage units higher in NSC than the diet with 17% FNDF. Without consideration of cows fed a diet with 25% FNDF after parturition, cows fed diets with 17% FNDF tended to have higher DMI as the percentage of BW (3.95 vs. 3.70%) than those fed diets with 21% FNDF. Cows fed 21% FDNF diets had higher intakes of FNDF and NSC but lower NDF intake than those fed diets with 17% FNDF. In contrast, Slater et al. (2000) reported no difference in DMI for cows at 60 DIM fed diets with 21% FNDF compared with those fed diets with 16% FNDF. Zhu et al. (1997) did not observe a difference in DMI at 56 DIM by cows fed diets with 21 and 17% FNDF. Harmison et al. (1997) reported that DMI decreased linearly as FNDF decreased from 21 to 11%, but most of the DMI reduction was when the level of FNDF dropped from 16 to 11%. Therefore, no adverse effect after 30 DIM would be expected if the cows were fed diets with 17% FNDF and soybean hulls. Consistent with this trial, Grant (1997) suggested that cows at more than 28 DIM can be fed up to 25% soybean hulls of dietary DM as a NFFS, and 20.8% soybean hulls were used in this trial. No effect was found for feeding cows 25 versus 17% FNDF with YC during the first 30 DIM on subsequent feed intakes during 31 to 140 DIM.

No effects of YC or an interaction of YC and FNDF on intakes of DM, FNDF, NDF, and NSC were observed during 31 and 140 DIM, but there tended to be an interaction of YC and FNDF concentration on CP intake. The CP intake tended to be higher for cows fed a diet with 21% FNDF and YC than without YC, but this relationship was reversed for cows fed diets with 17% FNDF. The effect of YC on DMI has been variable. Erasmus et al. (1992) and Wohlt et al. (1991) reported increased DMI with YC supplementation, but Arambel and Kent (1990) and Kamalamma et al. (1996) did not observe an effect of YC on DMI. Besides the factors of stage of lactation and basal diets fed, the viable yeast cell number in YC or amount of YC supplemented should also be considered (Kamalamma et al., 1996). Wohlt et al. (1998) demonstrated that an additional 10

Table 4. Effects of dietary forage NDF (FNDF) concentration and yeast culture (YC) supplementation on lactation performance and energy efficiency during the first 30 DIM.

	17% FNDF		21% FNDF		25% FNDF		Probability			
Item	No YC	YC	No YC	YC	YC	SE	YC[1]	FNDF*YC[1]	Linear[2]	Quadratic[2]
DMI										
kg/d	18.1	18.5	19.4	21.3	18.7	1.1	0.20	0.39	0.86	0.01
% of BW	3.18	3.20	3.30	3.52	3.33	0.16	0.42	0.50	0.57	0.17
FNDF intake, kg/d	3.08	3.13	4.09	4.49	4.68	0.22	0.22	0.33	<0.01	0.01
NDF intake, kg/d	6.51	6.33	5.95	6.21	5.74	0.35	0.88	0.45	0.15	0.62
CP intake, kg/d	3.44	3.50	3.63	4.13	3.56	0.18	0.09	0.25	0.94	0.01
NSC intake, kg/d	5.60	5.68	7.27	8.14	6.51	0.37	0.13	0.20	0.05	<0.01
Milk, kg/d	36.6	35.6	38.2	41.0	36.4	2.2	0.62	0.31	0.75	0.03
3.5% FCM, kg/d	39.8	39.4	41.5	43.8	39.2	2.5	0.61	0.48	0.92	0.05
ECM[3], kg/d	39.5	39.3	41.5	44.0	39.4	2.5	0.55	0.47	0.96	0.04
Milk fat, %	4.21	4.22	4.07	4.04	3.97	0.19	0.94	0.91	0.34	0.79
Milk protein, %	3.24	3.34	3.35	3.38	3.43	0.09	0.49	0.71	0.49	0.98
Milk fat, kg/d	1.48	1.48	1.54	1.61	1.44	0.10	0.64	0.67	0.71	0.13
Milk protein, kg/d	1.16	1.17	1.26	1.36	1.22	0.08	0.39	0.46	0.56	0.03
BW, kg	596	618	630	644	601	25	0.31	0.84	0.52	0.11
BW change, kg/d	−0.58	−0.32	−0.30	−0.42	−0.61	0.52	0.89	0.68	0.65	0.94
NE_L intake, Mcal/d	31.6	32.4	34.5	38.4	33.1	1.9	0.14	0.32	0.73	<0.01
NE_L output[4], Mcal/d	34.1	35.7	37.1	39.5	34.6	2.4	0.26	0.82	0.67	0.04
NE_L balance, Mcal/d	−2.47	−3.24	−2.59	−1.09	−1.51	1.86	0.83	0.52	0.49	0.55
NE_L efficiency[5]	1.17	1.16	1.11	1.03	1.07	0.08	0.58	0.61	0.34	0.33
PEE[6]	0.81	0.88	0.87	0.91	0.86	0.07	0.40	0.77	0.81	0.66

[1]21% FDNF without YC, 21% FNDF with YC, 17% FNDF without YC, and 17% FNDF with YC were used for contrasts.

[2]Linear and quadratic effects of FNDF using treatments with 17, 21, and 25% FNDF with YC.

[3]ECM = Energy-corrected milk, calculated based on the equation developed by Tyrrell and Reid (1965).

[4]NE_L output = NE_L for maintenance + NE_L for milk + NE_L for BW change.

[5]NE_L efficiency = NE_L output/NE_L intake.

[6]PEE = Partial efficiency of NE_L for lactation; PEE = (NE_L intake − NE_L for maintenance)/NE_L for milk.

Table 5. Effects of dietary forage NDF (FNDF) concentration and yeast culture (YC) supplementation on the lactation performance and energy efficiency between 31 and 140 DIM.

	17%FNDF		21% FNDF		25% FNDF[1]		Probability[2]			
Item	No YC	YC	No YC	YC	YC	SE	FNDF	YC	FNDF*YC	Transition
DMI										
kg/d	25.4	24.0	23.4	24.7	24.8	1.1	0.45	0.97	0.14	0.53
% of BW	4.08	3.81	3.63	3.77	4.06	0.13	0.06	0.63	0.12	0.20
FNDF intake, kg/d	4.33	4.07	4.93	5.10	4.35	0.23	<0.01	0.86	0.29	0.56
NDF intake, kg/d	8.93	8.42	7.14	7.10	8.54	0.38	<0.01	0.33	0.40	0.60
CP intake, kg/d	4.80	4.57	4.38	4.76	4.72	0.21	0.51	0.66	0.07	0.53
NSC intake, kg/d	7.89	7.42	8.76	9.38	7.64	0.39	<0.01	0.81	0.10	0.64
Milk, kg/d	43.6	41.1	41.7	45.6	42.2	2.4	0.52	0.73	0.11	0.71
3.5% FCM, kg/d	42.5	41.2	40.4	45.1	41.1	2.3	0.60	0.35	0.10	0.97
ECM,[3] kg/d	42.8	41.6	40.7	45.1	41.4	2.3	0.70	0.39	0.12	0.95
Milk fat, %	3.36	3.53	3.33	3.48	3.36	0.12	0.65	0.08	0.85	0.18
Milk protein, %	3.10	3.19	3.07	3.04	3.12	0.05	0.02	0.43	0.14	0.19
Milk fat, kg/d	1.45	1.44	1.38	1.57	1.41	0.08	0.70	0.16	0.12	0.70
Milk protein, kg/d	1.35	1.31	1.27	1.38	1.30	0.07	0.92	0.55	0.19	0.91
BW, kg	618	632	642	649	622	20	0.20	0.50	0.85	0.67
BW change, kg/d	0.14	0.14	0.29	–0.05	0.26	0.20	0.91	0.39	0.39	0.65
NE_L intake, Mcal/d	44.2	42.1	41.6	44.4	44.0	1.9	0.96	0.84	0.13	0.40
NE_L output[4], Mcal/d	40.4	39.1	38.9	41.8	39.7	1.7	0.68	0.56	0.13	0.78
NE_L balance, Mcal/d	3.91	2.99	2.73	2.65	3.72	1.09	0.48	0.64	0.70	0.63
NE_L efficiency[5]	0.93	0.95	0.97	0.98	0.93	0.03	0.22	0.62	0.87	0.53
PEE[6]	1.19	1.17	1.12	1.11	1.27	0.05	0.22	0.79	0.95	0.18

[1]Cows were fed 25% FNDF for 30 d and then switched to 17% FNDF with YC for 110 d.

[2]21 versus 17% FNDF, YC versus no YC, interaction between FNDF and YC, and transition: cows fed 17% FNDF with YC during 0 to 140 DIM versus cows fed 25% FNDF with YC during the first 30 DIM and 17% FNDF with YC during 31 to 140 DIM.

[3]ECM = Energy-corrected milk; calculated based on the equation developed by Tyrrell and Reid (1965).

[4]NE_L output = NE_L for maintenance + NE_L for milk + NE_L for BW change.

[5] NE_L efficiency = NE_L output/ NE_L intake.

[6]PEE = Partial efficiency of NE_L for milk; PEE = (NE_L intake − NE_L for maintenance)/ NE_L for milk.

g/d of YC at 29 DIM added to 10 g/d of YC fed from 30 d prepartum to 28 DIM increased DMI from 5 to 18 wk of lactation compared with removing the 10 g of YC/d at 29 DIM.

Milk Production and Feed Efficiency

A quadratic effect of FNDF on yields of milk (35.6, 41.0, and 36.4 kg/d), 3.5% FCM (39.4, 43.8, and 39.2 kg/d), ECM (39.3, 44.0, and 39.4 kg/d), and milk protein (1.17, 1.36, and 1.22 kg/d) was found for cows receiving YC-containing diets with 17, 21, and 25% FNDF, respectively, during the first 30 DIM (Table 4). The effect of dietary treatments on milk yield is in Figure 2. Cows fed the diets with 21% FNDF plus YC had the highest peak milk production among all treatments. The increased yields of milk and milk protein can probably be explained by the higher intakes of DM and NE_L by cows fed YC-containing diets with 21% FNDF than those with 17 or 25% FNDF. Consistent with the quadratic effect of FNDF on milk yield for cows fed 17, 21, and 25% FNDF diets, cows fed the 21% FNDF diet had the highest NE_L output.

No effect of YC on milk production was found during the first 30 DIM, which was consistent with the report by Soder and Holden (1999) and Wohlt et al. (1998) but not with another report by Wohlt et al. (1991). This may be because there was no effect of YC on DMI during the first 30 DIM. No interaction between dietary treatments and weeks of lactation occurred for milk yield, milk composition, and feed efficiency, but a time × treatment interaction was significant for NE_L output during 31 to 140 DIM. This interaction might have occurred

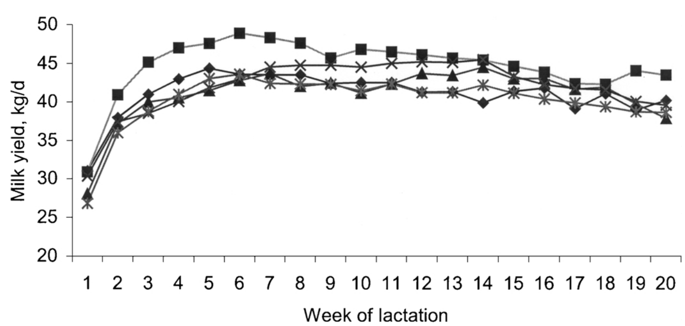

Figure 2. Milk yield for cows fed 21% forage NDF (FNDF) without yeast culture (YC) (◆), 21% FNDF with YC (■), 17% FNDF without YC (✖), 17% FNDF with YC (✳), and 25% FNDF with YC for the first 30 DIM and 17% FNDF with YC for 31 to 140 DIM (▲)(SEM = 2.2 for 1 to 30 DIM and 2.4 for 31 to 140 DIM).

because of the higher output during wk 5 through 8 for cows fed 21% FNDF with YC.

Feeding diets with 17% FNDF increased milk protein percentage (3.15 vs. 3.05%) compared with 21% FNDF during 31 and 140 DIM. These results do not agree with some studies (Harmison et al., 1997; Sarwar et al., 1992; Slater et al., 2000) but were similar to those in the study by Beauchemin and Rode (1997), who found that an 18.9% FNDF diet resulted in the highest milk yield and milk protein percentage but lowest energy efficiency among diets with 18.9, 24.5, and 39.9% FNDF. However, no NFFS were used, so NSC decreased as FNDF increased. Milk yield and milk protein percentage were increased when NFFS were used to reduce FNDF from 22.1 to 12%, but milk fat percentage decreased as FNDF decreased (Clark and Armentano, 1997). Feeding diets with 17% FNDF compared with 25% FNDF during the first 30 DIM did not affect animal performance and feed efficiency when cows were fed the diet with 17% FNDF plus YC during 31 to 140 DIM.

The effects of YC on milk yield and milk composition were generally not significant after 30 DIM. These results agreed with studies of Soder and Holden (1999) and Wohlt et al. (1991) but not with the study of Piva et al. (1993), who reported increased yields of milk and milk fat when cows in midlactation were fed YC in diets with 48% concentrate. Wohlt et al. (1998) showed that 20 g/d of YC tended to increase yields of milk, 3.5% FCM, and milk fat compared with diets without YC because of increased DMI and the higher digestibilities of CP and ADF. Feeding YC in our study tended to increase milk fat percentage. The interaction of FNDF concentration and YC approached significant trends (P = 0.10 to 0.14) for intakes of DM, CP, NSC, and NE_L; yields of milk, 3.5% FCM, ECM, and milk fat; milk protein percentage; and NE_L output during 31 to 140 DIM. Cows fed the diet with 21% FNDF appeared to have better responses to YC supplementation than did those fed the diet with 17% FNDF. Williams and Newbold (1990) suggested that the inclusion of YC in the diet resulted in the greatest response in animals fed high-concentrate diets. In the current trial, the total dietary NFC was even higher in the diets with 21% FNDF than with 17% FNDF (42.0 vs. 37.6%) because of large amount of soybean hulls in the low forage diets.

Body Weight, Body Condition Score, and Health

There were no effects from YC, FNDF concentration, and interaction between YC and FNDF concentration on BW and BW changes of cows during the first 30 DIM and the period between 31 and 140 DIM (Tables 4 and 5). Cows fed 17% FNDF with YC for 140 DIM did not result in any difference in BW and BW change compared with cows fed 25% FNDF with YC for the first 30 DIM and 17% FNDF with YC during 31 and 140 DIM. The average BCS during 0 to 140 DIM was 2.55, 2.83, 2.79, 2.91, and 2.93 (SE = 0.10) for cows fed 17% FNDF, 17% FNDF with YC, 21% FNDF, 21% FNDF with YC, and 25% FNDF with YC for 30 DIM and 17% FNDF with YC during 31 and 140 DIM, respectively, and no effects of treatments on BCS were observed. Around parturition, the BCS decreased for all cows during the first 30 DIM, but the average decrease in BCS during this period was numerically less for cows fed diets with YC than those without YC (0.31 vs. 0.82). Robinson (1997) found that 57 g/d of YC lessened the BCS loss prepartum, but YC has been observed to have no effect on BCS after parturition (Robinson, 1997; Robinson and Garrett, 1999; Soder and Holden, 1999).

No metabolic diseases were observed with cows receiving 21% FNDF, but four cows supplemented with YC had a left displaced abomasum and two cows without YC had ketosis when they were fed 17% FNDF. Services per conception were 1.8, 2.5, 2.3, and 1.9 and days open were 91, 137, 114, and 109 for cows fed YC, without YC, 21% FNDF, and 17% FDNF, respectively. However, conclusions from these observations are tenuous.

CONCLUSIONS

A quadratic effect for 17, 21, and 25% FNDF on intakes of DM, NE_L, and CP and yields of milk and milk protein was observed when YC was in the diets during the first 30 DIM. Because there was no interaction between YC and FNDF level, diets with 21% FNDF provided higher intakes of energy and CP and, hence, supported higher yields of milk and milk protein than diets with 25 or 17% FNDF during the first 30 DIM. From 31 to 140 DIM, diets with 17% FNDF tended to result in higher DMI as the percentage of BW and resulted in higher milk protein percentage than diets with 21% FNDF. From 31 to 140 DIM, YC supplementation of diets with 21% FNDF appeared to result in higher response on yields of milk and milk fat than YC in diets with 17% FNDF.

In conclusion, the diets with 21% FNDF may be better for cows during the first 30 DIM. After peak lactation, however, 17% FNDF was sufficient to maintain DMI and milk production of cows when total NDF was more than 30% of dietary DM. Although FNDF can be used as an index of effective fiber, particle size of the forages must also be monitored. Adequate particle size of forages is very critical in diets with low FDNF. Even though NSC concentration differed when dietary FNDF concentration changed, diets in this trial were formulated to maintain the FNDF:NSC ratio at more than

0.5. It is important to reduce the NSC concentration when the concentration of FNDF is decreased, and, therefore, the effect of FNDF on animal performance should be evaluated in conjunction with dietary NSC concentration.

ACKNOWLEDGMENTS

The authors thank Sue Zhang and undergraduate students in the lab for assistance with feed analyses. Also, thanks to Andy Spring, John Lemmermen, and the farm crew for care of the cows.

REFERENCES

Arambel, M. J., and B. A. Kent. 1990. Effect of yeast culture on nutrient digestibility and milk yield response in early to midlactation dairy cows. J. Dairy Sci. 73:1560–1563.

Association of Official Analytical Chemists. 1990. Official Methods of Analysis. Vol. I. 15th ed. AOAC, Arlington VA.

Beauchemin, K. A., and L. M. Rode. 1997. Minimum versus optimum concentrations of fiber in dairy cow diets based on barley silage and concentrates of barley or corn. J. Dairy Sci. 80:1629–1639.

Carro, M. D., P. Lebzien, and K. Rohr. 1992. Effects of yeast culture on rumen fermentation, digestibility and duodenal flow in dairy cows fed a silage based diet. Livest. Prod. Sci. 32:219–229.

Clark, P. W., and J. L. Armentano. 1993. Effectiveness of neutral detergent fiber in whole cottonseed and dried distillers grains compared with alfalfa haylage. J. Dairy Sci. 76:2644–2650.

Clark, P. W., and L. E. Armentano. 1997. Replacement of alfalfa neutral detergent fiber with a combination of nonforage fiber sources. J. Dairy Sci. 80:675–680.

Dirksen, G. U., H. G. Liebich, and E. Mayer. 1985. Adaptive changes of the ruminal mucosa and their functional and clinical significance. Bovine Pract. 20:116–120.

Edmonson, A. J., I. J. Lean, L. D. Weaver, T. Farver, and G. Webster. 1989. A body condition scoring chart for Holstein dairy cows. J. Dairy Sci. 72:68–78.

Erasmus, L. J., P. M. Botha, and A. Kistner. 1992. Effect of yeast culture supplement on production, rumen fermentation, and duodenal nitrogen flow in dairy cows. J. Dairy Sci. 75:3056–3065.

Grant, R. J. 1997. Interactions among forages and nonforage fiber sources. J. Dairy Sci. 80:1438–1446.

Harmison, B., M. L. Eastridge, and J. L. Firkins. 1997. Effect of percentage of dietary forage neutral detergent fiber and source of starch on performance of lactating Jersey cows. J. Dairy Sci. 80:905–911.

Huntington, G. B., R. A. Britton, and R. L. Prior. 1981. Feed intake, rumen fluid volume and turnover, nitrogen and mineral balance and acid-base status of wethers changed from low to high concentrate diets. J. Anim. Sci. 52:1376–1387.

Kamalamma, U. Krishnamoorthy, and P. Krishnappa. 1996. Effect of feeding yeast culture (Yea-sacc[1026]) on rumen fermentation in vitro and production performance in crossbred dairy cows. Anim. Feed Sci. Technol. 57:247–256.

Minor, D. J., S. L. Trower, B. D. Strang, R. D. Shaver, and R. R. Grummer. 1998. Effects of nonfiber carbohydrate and niacin on periparturient metabolic status and lactation of dairy cows. J. Dairy Sci. 81:189–200.

National Research Council. 1989. Nutrient requirements of dairy cattle. 6th rev. ed. National Acad. Sci., Washington, DC.

Nisbet, D. J., and S. A. Martin. 1991. Effect of a *Saccaromyces cerevisiae* culture on lactate utilization by the ruminal bacterium *Selenomonas ruminantium.* J. Anim. Sci. 69:4628–4633.

Piva, G., S. Belladonna, G. Fusconi, and F. Sicbaldi. 1993. Effects of yeast on dairy cow performance, ruminal fermentation, blood components, and milk manufacturing properties. J. Dairy Sci. 76:2717–2722.

Plata, P. F., M.G.D. Mendoza, G.J.R. Barcena, and M. S. Gonzalez. 1994. Effect of a yeast culture (*Saccharomyces cerevisiae*) on neutral detergent fiber digestion in steers fed oat straw based diets. Anim. Feed Sci. Technol. 49:203–210.

Putnam, D. E., C. G. Schwab, M. T. Socha, N. L. Whitehouse, N. A. Kierstead, and B. D. Garthwaite. 1997. Effect of yeast culture in the diets of early lactation dairy cows on ruminal fermentation and passage of nitrogen fractions and amino acids to the small intestine. J. Dairy Sci. 80:374–384.

Robinson, P. H. 1997. Effect of yeast culture (*Saccharomyces cerevisiae*) on adaptation of cows to diets postpartum. J. Dairy Sci. 80:1119–1125.

Robinson, P. H., and J. E. Garrett. 1999. Effect of yeast culture (*Saccharomyces cerevisiae*) on adaptation of cows to postpartum diets and on lactational performance. J. Anim. Sci. 77:988–999.

Ruiz, T. M., E. Bernal, C. R. Staples, L. E. Sollenberger, and R. N. Gallaher. 1995. Effect of dietary neutral detergent fiber concentration and forage source on performance of lactating cows. J. Dairy Sci. 78:305–319.

Sarwar, M., J. L. Firkins, and M. L. Eastridge. 1992. Effects of varying forage and concentrate carbohydrates on nutrient digestibilities and milk production by dairy cows. J. Dairy Sci. 75:1533–1542.

SAS/STAT Software. Changes and Enhancements through Release 6.12. 1997. SAS Inst., Inc. Cary, NC.

Slater, A. L, M. L. Eastridge, J. L. Firkins, and L. J. Bidinger. 2000. Effect of starch source and level of forage neutral detergent fiber on performance by dairy cows. J. Dairy Sci. 83:313–321.

Soder, K. J., and L. A. Holden. 1999. Dry matter intake and milk yield and composition of cows fed yeast prepartum and postpartum. J. Dairy Sci. 82:605–610.

Sukhija, P. S., and D. L. Palmquist. 1988. Rapid method for determination of total fatty acid content and composition of feedstuffs and feces. J. Agric. Food Chem. 36:1202–1206.

Swain, S. M., and L. A. Armentano. 1994. Quantitative evaluation of fiber from nonforage sources used to replace alfalfa silage. J. Dairy Sci. 77:2318–2331.

Swartz, D. L., L. D. Muller, G. W. Rogers, and G. A. Varga. 1994. Effect of yeast cultures on performance of lactating dairy cows: A field study. J. Dairy Sci. 77:3073–3080.

Tyrrell, H. F., and J. T. Reid. 1965. Prediction of the energy values of cow's milk. J. Dairy Sci. 48:1215–1223.

Van Soest, P. J., J. B. Robertson, and B. A. Lewis. 1991. Methods for dietary fiber, neutral detergent fiber, and nonstarch polysaccharides in relation to animal nutrition. J. Dairy Sci. 74:3583–3597.

Wallace, R. J. 1994. Ruminal microbiology, biotechnology, and ruminant nutrition: progress and problems. J. Anim. Sci. 72:2992–3003.

Wallace, R. J., and C. J. Newbold. 1993. Rumen fermentation and its manipulation: the development of yeast cultures as feed additives. Pages 173–192 *in* Biotechnology in the Feed Industry. T. P. Lyons ed., Alltech Technical Publications, Nicholasville, KY.

Weiss, W. P. 1998. Estimating available energy content of feeds for dairy cattle. J. Dairy Sci. 81:830–839.

Williams, P.E.V., and C. J. Newbold. 1990. Rumen probiosis: the effects of novel microorganisms on rumen fermentation and ruminant productivity. Pages 211–226 *in* Recent Advances in Animal Nutrition. W. Haresign and D. J. A. Cole, ed. Butterworths, London, England.

Wohlt, J. E., T. T. Corcione, and P. K. Zajac. 1998. Effect of yeast on feed intake and performance of cows fed diets based on corn silage during early lactation. J. Dairy Sci. 81:1345–1352.

Wohlt, J. E., A. D. Finkelstein, and C. H. Chung. 1991. Yeast culture to improve intake, nutrient digestibility, and performance by dairy cattle during early lactation. J. Dairy Sci. 74:1395–1400.

Zhu, J. S., S. R. Stokes, and M. R. Murphy. 1997. Substitution of neutral detergent fiber from forage with neutral detergent fiber from by-products in the diets of lactating cows. J. Dairy Sci. 80:2901–2906.