Reprinted from the *Journal of Production Agriculture*
Volume 6, no. 2, April–June 1993
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Model-Predicted Value of Enzyme-Treated Alfalfa Silage for Lactating Dairy Cows

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A model containing a mechanistic rumen submodel sensitive to variations in feed carbohydrate fractions was used to determine the potential value for lactating dairy cattle (*Bos taurus*) of treating alfalfa (*Medicago sativa* L.) silage with enzymes that reduce neutral detergent fiber (NDF) concentration. The net carbohydrate and protein system used here integrates nutrient intake, ruminal fermentation, intestinal digestion, absorption, and metabolism with cattle requirements. For each of a series of potential effects of enzyme treatment, the treatment value per ton of silage was determined either from a reduction in diet costs or an increase in milk production calculated from increasing the supply of metabolizable energy (ME). Balanced rations were formulated from corn (*Zea mays* L.) silage, alfalfa silage, ground dry corn grain, high moisture ear corn, soybean [*Glycine max* Merr. L.] meal, and heat-treated soybean meal for early- and mid-lactation cows. Potential reductions in NDF effected by enzyme treatment were considered to be 2, 4, or 6 percentage points. In Scenario 1, diets were rebalanced as NDF was reduced, while maximizing the use of alfalfa silage and minimizing the use of corn grain. In Scenario 2, diets were held constant, and the increase in ME as a result of enzyme treatment was used to calculate a potential increase in milk production. In Scenario 3, dry matter intake (DMI) was increased to maintain a fixed intake of effective NDF (eNDF), and the ME-allowed increase in milk production was calculated. Additionally, an increase in the rate of fiber digestion from 7 to 9%/h was considered in Scenario 3. Reduction in diet costs in Scenario 1 resulted in treatment values of less than $1/ton silage. Increases in milk production in Scenario 2 resulted in treatment values of $2.60 to $4.80/ton silage for a 4 percentage point reduction in NDF. In the most optimistic cases (Scenario 3), treatment values were as high as $40/ton with a 4 percentage point reduction in NDF. The model predicts that a production response is necessary to obtain substantial economic benefit from enzyme treatment of silage. Treatment values were higher with a larger NDF reduction, with a higher milk price, and with more mature alfalfa.

HARVESTING ALFALFA with high fiber content is a problem that arises when weather is unfavorable at the time of optimum maturity. The detrimental effects of high fiber content on animal production include reduced DMI, lower available energy in the forage, and lower rates of gain or milk production in dairy cattle (Van Soest, 1982; National Research Council, 1989). Addition of enzymes at ensiling can reduce fiber concentrations during storage. Commercially available enzymes generally consist of cellulases, hemicellulases, pectinases, or amylases. The hydrolysis of plant structural carbohydrates (SC) to non-structural carbohydrates (NSC) should, in theory, increase the growth of NSC-fermenting bacteria in the rumen and increase the energy derived from the forage.

In grass silages, NDF reductions of 1 to 5 percentage points have been measured (Jaakola, 1990; van Vuuren et al., 1989; Jaakola et al., 1991). Jaster and Moore (1990) observed no change in cellulose or hemicellulose contents over only 27 d storage. Acid detergent fiber (ADF) reductions were correlated with NDF reductions but were lesser in extent (van Vuuren et al., 1989; Jacobs and McAllan, 1991; Jaakola, 1990).

Experiments on enzyme treatment of alfalfa have had mixed results. Interpretation of these results is complicated by differences in ensiling conditions and enzyme mixtures used in different trials. With wilted alfalfa, Kung et al. (1991) found that addition of a cellulase/pectinase enzyme complex had no effect on NDF and ADF. Addition of cellulase at 500 times the commercial dose decreased NDF by 6.6 percentage points in controlled in vitro conditions (pH 4.5, 122 °F, 50 d incubation). Only minor changes in NDF and ADF were observed when a cellulase complex was added at 50 times the commercial dose to unwilted or wilted silage. Stokes (1992) observed reductions of 6 percentage points in alfalfa NDF and 2 percentage points in ADF when a cellulase mixture was used without an innoculant, but differences in composition of control and treated forages make these results difficult to interpret. A model of cellulase additives in silage (Pitt, 1990) suggested that cellulase activity was lower in silage than on idealized substrates, and that high application rates and long storage times would be needed to compensate for reduced activity.

Enzymes in commercial additives neither degrade lignin nor hydrolyze ligno-cellulose bonds, and reported reductions in NDF and ADF with enzyme treatment have not been associated with reductions in lignin content (Jaakola, 1990). Thus, lignin accounts for a higher per-

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Published in J. Prod. Agric. 6:280–286 (1993).

Abbreviations: ADF, acid detergent fiber; DM, dry matter; DMI, dry matter intake; DOM, digestible organic matter; eNDF, effective neutral detergent fiber; HMEC, high moisture ear corn; ME, metabolizable energy; MP, metabolizable protein; NDF, neutral detergent fiber; NSC, non-structural carbohydrates; SBM, soybean meal; SC, structural carbohydrates.

Table 1. Composition and cost of feeds in the diet.

	Corn silage	Corn dry grain	HMEC	SBM	Heat-treated SBM	Untreated alfalfa silages: Early-bloom	Mid-bloom, low NDF	Mid-bloom, medium NDF	Mid-bloom, high NDF
NDF, % DM	42.9†	9.0†	28.0†	14.0†	23.0†	42.0†	46.0	51.0	57.0†
Effective NDF, % NDF	71.0	48.0	56.0	23.0	23.0	80.0	90.0	90.0	90.0
Crude protein, % DM	9.5†	10.1†	8.1†	49.0†	48.0†	21.1†	17.1	17.1	17.1†
Soluble, % CP	56.7†	11.0†	30.0†	20.0†	8.0†	61.0†	45.0	45.0	45.0†
ADF insoluble, % CP	7.9†	5.0†	8.3†	5.0†	2.0†	7.1†	18.0	18.0	18.0†
NDF insoluble, % CP	16.4†	15.0†	18.7†	10.0†	35.0†	26.7†	32.0	32.0	32.0†
Fat, % DM	3.5	4.3	3.7	1.5	5.3	3.2	2.7	2.7	2.7
Ash, % DM	4.2	1.6	1.9	7.3	6.7	10.1	9.6	9.6	9.6
Carbohydrate (CHO), % DM	82.8	84.0	86.3	42.2	40.0	65.6	70.6	70.6	70.6
Unavailable fiber, % CHO	8.7	2.8	5.5	2.4	1.7	30.7	32.2	35.7	39.9
Available fiber (B2), % CHO	41.2	6.1	25.2	19.2	13.8	24.7	25.2	28.8	33.1
NSC, % CHO	50.0	91.1	69.3	78.4	84.5	44.6	42.6	35.5	27.0
Cost, $/ton as-fed	22.0	116.0	71.0	200.0	245.0	31.0	31.0	31.0	31.0

† Based on actual feed analysis (Fox et al., 1990).

centage of NDF and ADF after enzymatic action. With grass silages, the digestibilities of NDF and ADF decreased with enzyme treatment in trials with sheep (Jaakola, 1990), cannulated cows (van Vuuren et al., 1989), and steers (Jacobs and McAllan, 1991). Jaakola et al. (1991), however, observed no effect on digestibility of NDF and ADF, possibly indicating that the degradability of the unhydrolyzed fiber was increased by the enzymes. Kung et al. (1992) found that enzyme treatment of alfalfa had no effect on rate of NDF digestion and decreased the extent of NDF digestion.

In diets where rumen fill limits intake, enzyme treatments can potentially increase DMI (Muller et al., 1972; Tomlinson et al., 1991). Jaakola (1990) observed an increase in DMI with sheep (*Ovis aries*) fed enzyme-treated grass silage, whereas Jacobs and McAllan (1991) found no effect on DMI in steers. Chamberlain and Robertson (1988) reported higher milk yields with enzyme-treated grass silage. Stokes (1992) found increases in DMI of 4.4 lb/d and in milk production of 1.6 lb/d for multiparous cows fed total mixed rations containing enzyme-treated alfalfa silage. Increases in weight gain also were observed. Enzyme treatment of a grass/legume mixture was associated with increases in DMI of 3.2% and in milk yield of 6.2% (Chen and Stokes, 1992).

The objective of this study was to estimate, using a mechanistic model of cattle digestion and production, the potential value of cell-wall degrading enzymes for lactating dairy cows. Two aspects of enzyme treatment were considered: (i) the potential use of enzyme-treated alfalfa to replace corn grain, and (ii) the potential increase in milk production. This study examined a sequence of scenarios spanning the observed range of enzyme effectiveness, but did not theorize which of these scenarios would occur. The extent and type of effect the treatment would need to have to offset the treatment cost were predicted.

MATERIALS AND METHODS

The Net Carbohydrate and Protein System

The net carbohydrate and protein system (Ainslie et al., 1993; Fox et al., 1990, 1992; O'Connor et al., 1993; Russell et al., 1992; Sniffen et al., 1992) predicts cattle nutrient requirements and feed use to meet these requirements as dependent on animal, environmental, feedstuff, and management factors. Based on empirical equations from the National Research Council (1984, 1985, 1989) and the literature, the model incorporates nutrient intake, ruminal fermentation, intestinal digestion, absorption, and metabolism, and integrates these factors with cattle requirements as dependent on production level and environmental conditions. The system of equations describes the transformations of nutrients and energy, in steady-state, for microbial growth, animal metabolism, and production of endproducts. Central to the model is a rumen submodel that uses mechanistic principles, feed chemical entities, and their characteristic digestion rates to predict carbohydrate and protein fermentation, microbial growth, and usable energy and protein yields under varying conditions. Use of the model to estimate the effects of silage protein solubility was described by Knowlton et al. (1992).

The net carbohydrate and protein system was used for this study because (i) it considers the dynamic character of animal digestion of feedstuffs, which is of critical importance in fiber digestion; and (ii) the model has been extensively validated. Validation trials comparing predicted and in vitro flows of microbial N from the rumen have shown a coefficient of determination (r^2) of 0.90 with minimal bias (Chalupa et al., 1991; O'Connor et al., 1993). Trials comparing predicted and actual weight gains of Holstein calves produced an r^2 of 0.57 with minimal bias (Ainslie et al., 1993). Predicted total excess N of lactating dairy cattle was linearly related to measured plasma urea N concentration with an r^2 of 0.92 (Elrod, 1992).

Assumptions

The study was based on the production level, feed ingredients and DMI of a commercial Holstein herd in New York State, which had a rolling herd average of 19 740 lb milk averaging 3.7% fat and 3.1% protein. Nutrient and energy requirements were generated and diets were formulated for early- and mid-lactation multiparous cow groups. Nutrient requirements for the two cow groups, respectively, were 47.7 and 37.9 lb dry matter (DM)/d; 56.2 and 40.6 Mcal/d of ME; 1.18 and 1.07 Mcal/lb of energy density in the diet; 5.2 and 3.7 lb/d of metabolizable protein (MP); 9.5 and 7.6 lb/d of eNDF, which is

Table 2. Composition of balanced diets and value of the enzyme treatment for the early-lactation cow group (Scenario 1).

	NDF of alfalfa silage, % DM			
	Untreated 46	44	42	40
Diet constituents, lb DM/d				
Corn silage	15.70	15.70	15.70	15.70
Legume silage	9.0	9.15	9.31	9.48
Corn dry grain	10.88	10.70	10.52	10.33
HMEC	6.10	6.10	6.10	6.10
SBM	3.18	3.18	3.18	3.18
Heat-treated SBM	2.85	2.87	2.89	2.91
Total DMI, lb/d	47.71	47.70	47.70	47.70
eNDF, lb/d	10.2	10.1	10.0	9.9
ME, Mcal/lb DM	0.96	0.97	0.98	0.99
Diet cost, $/d	2.679	2.676	2.673	2.670
Treatment value, $/ton silage	--	0.25	0.45	0.67

Table 3. Composition of balanced diets and value of the enzyme treatment for the mid-lactation cow group (Scenario 1).

	NDF of alfalfa silage, % DM			
	Untreated 51	49	47	45
Diet constituents, lb DM/d				
Corn silage	15.00	15.00	15.00	15.00
Legume silage	12.53	12.72	12.93	13.14
Corn dry grain	6.94	6.80	6.64	6.49
HMEC	0.0	0.0	0.0	0.0
SBM	3.10	3.10	3.10	3.10
Heat-treated SBM	0.35	0.30	0.25	0.19
Total DMI, lb/d	37.92	37.92	37.92	37.92
eNDF, lb/d	10.7	10.6	10.4	10.3
ME, Mcal/lb DM	0.92	0.93	0.93	0.94
Diet cost, $/d	1.884	1.875	1.867	1.857
Treatment value, $/ton silage	--	0.50	1.01	1.55

adjusted for particle size (Fox et al., 1990); 0.79 and 0.65 lb/d of N for ruminal bacteria; and 0.38 and 0.29 lb/d of peptide N for ruminal bacteria. Rumen capacities were 11.7 and 11.0 lb eNDF/d for the two cow groups, respectively. Average age was 41 mo, body weights were 1300 and 1310 lb, days pregnant 0 and 112, days since calving 113 and 232, milk production 80 and 43 lb/d, milk fat 3.5 and 3.8%, and milk protein 3.0 and 3.3%, respectively, for early- and mid-lactation groups. Ambient temperature was 50°F, with no wind or other source of environmental stress.

Rations were formulated from corn silage, alfalfa silage, ground dry corn grain, high moisture ear corn (HMEC), soybean meal (SBM), and heat-treated SBM, a source of undegraded intake protein. Table 1 contains feed composition values and costs (Fox et al., 1990). The impact of NDF levels associated with different maturities was considered for the alfalfa silage component of the diet. Crude protein levels, protein solubilities, available fiber levels, and levels of NSC also varied across the different alfalfa silages.

Ration Balancing

As currently implemented, the net carbohydrate and protein system does not automatically balance or optimize diets. Diets were formulated based on the following procedure and were considered balanced if all of the following criteria were met: (i) ME provided by the diet was above the animal's requirement and at a level that would increase body reserves at a rate of one point of body condition score (on a nine-point scale) in 100 d, (ii) MP provided by the diet was within ±0.002 lb/d of animal requirements, (iii) eNDF was above requirement and below capacity, (iv) the energy required to excrete excess dietary N (ruminal and absorbed) was below 0.5 Mcal/d, (v) N supplied for ruminal bacteria was above and within 30% of requirement (see below), (vi) peptides supplied for ruminal bacteria were less than 12% below requirement (see below), and (vii) DMI was within 0.2% of the requirement calculated by the model from body mass, milk production, milkfat percentage, and ambient temperature.

Acceptable ranges for ruminal ammonia and peptide balances in the model have not been established. It was assumed that if ruminal ammonia balance was 0 to 30% above requirement and ruminal peptides were less than 12% below requirement, the total ruminal N supply would be adequate. Excess bacterial N was presumed to compensate, in part, for the shortage of peptides.

When the NDF content of the alfalfa silage was decreased due to enzyme treatment and the diet was reformulated to maximize the use of alfalfa silage and reduce the use of corn grain, the procedure for rebalancing was as follows. First, corn grain was removed from the diet and replaced with alfalfa silage until the ME reached the same level as in rations with the untreated silage. If MP was below or above requirement, heat-treated SBM was adjusted accordingly, since it has a similar density of ME as corn grain. The levels of corn silage, HMEC, and unheated SBM were held constant as alfalfa silage NDF level was decreased and the diet was rebalanced.

Scenarios

Potential NDF reductions of 2, 4, and 6 percentage points were considered. Three possible effects of these reductions were analyzed in a sequence of scenarios of increasing effectiveness of the enzyme treatment. The goal was to determine the minimum effect needed to offset the cost of the treatment, not to hypothesize the most likely effect.

Scenario 1: Rebalanced diets. With decreased NDF and increased NSC concentrations in the alfalfa silage, diets were rebalanced assuming no production response by the cow. A reduction in diet costs was attributed to the enzyme treatment, and the economic value of the treatment per ton of silage was calculated.

Scenario 2: Increased milk production. With no change in the original diet, the increase in NSC concentration caused by enzyme treatment was used by the model to calculate the maximum increase in milk production based on ME availability. The economic value of the increased milk was calculated at $10, $12, and $14/cwt milk prices, and the treatment value per ton of silage was calculated.

Scenario 3: Increased DMI and milk production. The reduction in NDF was assumed to increase passage rate and therefore to increase DMI. With each decrease in alfalfa silage NDF concentration, whole-diet DMI was increased to the same level of intake of eNDF as in the original diet, with the proportion of each component of

Table 4. Effect of initial alfalfa NDF on savings in diet costs in Scenario 1 and on milk production, DMI, and treatment values in Scenarios 2 and 3; early-lactation cow group.

	NDF reduction due to enzyme treatment, percentage points											
	2				4				6			
Initial NDF:	42	46	51	57	42	46	51	57	42	46	51	57
	Scenario 1											
Savings in diet costs, \$/ton silage	0.11	0.25	0.19	0.17	0.25	0.45	0.38	0.32	0.43	0.67	0.51	0.48
	Scenario 2											
Predicted increase in milk production, lb/d	0.17	0.12	0.19	0.18	0.34	0.40	0.39	0.37	0.51	0.60	0.58	0.56
Treatment value (\$12/cwt milk), \$/ton silage	1.54	2.02	1.94	1.86	3.11	4.09	3.93	3.76	4.68	6.12	5.93	5.68
	Scenario 3											
Predicted increase in DMI, lb/d	0.73	0.76	0.77	0.76	1.46	1.58	1.54	1.57	2.20	2.41	2.37	2.35
Predicted increase in milk production, lb/d	1.80	1.90	1.91	1.88	3.60	3.95	3.84	3.88	5.45	6.03	5.91	5.82
Treatment value (\$12/cwt milk), \$/ton silage	13.01	15.49	15.43	15.14	25.72	31.48	30.52	30.67	38.46	47.34	46.14	45.30

Table 5. Effect and value of reducing NDF on ME-allowed milk production for the early-lactation cow group (Scenario 2). Original diet as in column 1, Table 2.

	NDF of alfalfa silage, % DM			
	Untreated 46	44	42	40
Legume silage				
K_p, %/h	4.13	4.20	4.27	4.34
Rumen degraded:				
NSC, lb/100 lb DM	29.3	31.3	33.2	35.2
SC, lb/100 lb DM	11.2	9.9	8.6	7.3
DOM†, lb/100 lb DM	51.7	52.3	52.9	53.5
ME, Mcal/lb DM	0.96	0.97	0.98	0.99
NSC bacteria, lb/100 lb DOM	21.4	22.2	23.1	23.8
SC bacteria, lb/100 lb DOM	6.2	5.3	4.5	3.8
Total bacteria, lb/100 lb DOM	27.6	27.5	27.6	27.6
ME balance, Mcal/d	3.4	3.5	3.6	3.7
MP balance, lb/d	0.0	−0.0044	−0.0110	−0.0154
eNDF, lb/d	10.2	10.0	9.9	9.7
Predicted increase in milk production, lb/d	0.0	0.20	0.40	0.60
Treatment value, \$/ton silage				
\$10/cwt milk	--	1.68	3.41	5.10
\$12/cwt milk	--	2.02	4.09	6.12
\$14/cwt milk	--	2.35	4.77	7.14

† DOM = digestible organic matter.

Table 6. Effect and value of reducing NDF on ME-allowed milk production for the early-lactation cow group (Scenario 2). Original diet as in column 1, Table 3.

	NDF of alfalfa silage, % DM			
	Untreated 51	49	47	45
Legume silage				
K_p, %/h	3.52	3.57	3.63	3.69
Rumen degraded:				
NSC, lb/100 lb DM	24.5	26.5	28.4	30.4
SC, lb/100 lb DM	13.5	12.1	10.7	9.4
DOM†, lb/100 lb DM	49.4	50.0	50.5	51.1
ME, Mcal/lb DM	0.92	0.93	0.93	0.94
NSC bacteria, lb/100 lb DOM	21.0	22.4	23.7	25.0
SC bacteria, lb/100 lb DOM	8.5	7.5	6.6	5.7
Total bacteria, lb/100 lb DOM	29.5	29.9	30.3	30.7
ME balance, Mcal/d	3.6	3.7	3.9	4.0
MP balance, lb/d	0.0	0.0198	0.0419	0.0639
eNDF, lb/d	10.7	10.5	10.3	10.1
Predicted increase in milk production, lb/d	0.0	0.22	0.44	0.66
Treatment value, \$/ton silage				
\$10/cwt milk	--	1.32	2.65	3.99
\$12/cwt milk	--	1.58	3.18	4.78
\$14/cwt milk	--	1.85	3.71	5.58

† DOM = digestible organic matter.

the diet held fixed. In addition to higher NSC content in the alfalfa silage, the increased DMI allowed a further increase in ME-allowed milk production. The economic value of the treatment per ton of silage was calculated from the value of extra milk (at each price level) minus the increased diet costs.

As an adjunct to Scenario 3, it was further assumed that enzyme treatment both hydrolyzed NDF and made the unhydrolyzed NDF more digestible. The digestion coefficient (K_d) for the available fiber fraction of the alfalfa silage, which was initially 7%/h, was increased to 9%/h, the highest value for alfalfa silages given by Fox et al. (1990). Diet composition again was held constant, and increases in ME-allowed milk production with various levels of NDF reduction were calculated. This was examined only for the early lactation cow group.

RESULTS

Scenario 1: Rebalanced diets

Balanced diets formulated with the model with various NDF levels are shown in Tables 2 and 3 for the early- and mid-lactation cow groups, respectively. In the initial diet for the early-lactation cows, forages represented 52% of the diet, and alfalfa silage was 36% of the forage; for the mid-lactation cows, these numbers were 73% and 46%, respectively. As NDF was enzymatically decreased, the amount of legume silage was increased from 19 to 20% of the diet for the early-lactation group, and from 33 to 35% for the mid-lactation group. Corn dry grain was decreased with enzyme treatment. With decreased NDF, the amount of heat-treated SBM was increased to meet the MP requirement for early-lactation cows; in contrast, for mid-lactation cows the amount of heat-treated SBM was decreased. These contrasting results for the two cow groups were due to the competing effects of enzyme treatment. Reduction in fiber with enzyme treatment increased NSC available for growth of ruminal bacteria, but also increased the rate of passage of digesta through the rumen (see explanation in Scenario 2).

For both cow groups, diet costs were reduced as NDF content was decreased by enzyme treatment. The value of the treatment, however, was below \$1.55/ton of silage, even for the most extreme effect of the enzyme (6 percentage points reduction in NDF). This value is below the current cost of treatment needed for this reduction.

Table 7. Effect of reducing NDF and allowing DMI to increase to original level of eNDF intake on milk production and value of enzyme treatment for the early-lactation cow group (Scenario 3). Original diet as in column 1, Table 2. Adjusted treatment values are for a 1/3 increase in projected milk production.

	NDF of alfalfa silage, % DM			
	Untreated 46	44	42	40
DMI, lb/d	47.71	48.47	49.29	50.12
ME balance, Mcal/d	3.4	4.3	5.3	6.3
MP balance, lb/d	0.0	0.0573	0.1211	0.1850
eNDF, lb/d	10.2	10.2	10.2	10.2
Predicted increase in milk production, lb/d	0.0	1.90	3.95	6.03
Treatment value, $/ton silage				
$10/cwt milk	--	12.33	25.46	37.64
$12/cwt milk	--	15.49	31.48	47.34
$14/cwt milk	--	18.66	37.93	57.04
Adjusted treatment value, $/ton silage				
$10/cwt milk	--	4.11	8.49	12.55
$12/cwt milk	--	5.16	10.49	15.78
$14/cwt milk	--	6.22	12.64	19.01

Table 8. Effect of reducing NDF and allowing DMI to increase to original level of eNDF intake on milk production and value of enzyme treatment for the mid-lactation cow group (Scenario 3). Original diet as in column 1, Table 3. Adjusted treatment values are for a 1/3 increase in projected milk production.

	NDF of alfalfa silage, % DM			
	Untreated 51	49	47	45
DMI, lb/d	37.92	38.75	39.60	40.47
ME balance, Mcal/d	3.6	4.6	5.6	6.6
MP balance, lb/d	0.0	0.0771	0.1542	0.2379
eNDF, lb/d	10.7	10.7	10.7	10.7
Predicted increase in milk production, lb/d	0.0	1.88	3.83	5.81
Treatment value, $/ton silage				
$10/cwt milk	--	8.72	17.40	25.86
$12/cwt milk	--	10.95	21.85	32.47
$14/cwt milk	--	13.19	26.29	39.08
Adjusted treatment value, $/ton silage				
$10/cwt milk	--	2.91	5.80	8.62
$12/cwt milk	--	3.65	7.28	10.82
$14/cwt milk	--	4.40	8.76	13.03

The diets in Tables 2 and 3 used the low and medium NDF midbloom alfalfa silages, respectively, in the rations. The value of the enzyme treatment varied when other alfalfa silages were used in rebalanced rations (Table 4). For the early-lactation cows, enzyme treatment was most valuable for the 46% NDF silage and was least valuable for the 42% NDF silage. For the mid-lactation cows, the value of the treatment was slightly greater for the 51% NDF silage than for the 57% NDF silage (Knowlton et al., 1991).

Enzyme treatment was predicted to be more valuable in the diets of mid-lactation cows than in those of early-lactation cows, even when the same silage was used in both diets. For example, for the 51% NDF silage with a 4 percentage point decrease, enzyme treatment was valued at $0.38/ton for early lactation and $1.01/ton for mid-lactation. This was because (i) more alfalfa silage was used in the initial diets of the mid-lactation cows than in the early-lactation cows, (ii) a greater increase in the use of alfalfa silage was possible with NDF reduction for the mid-lactation cows, followed by a concomitantly greater decrease in corn grain, and (iii) heat-treated SBM had to be increased with enzyme treatment of the alfalfa in the diets of early-lactation cows (to provide sufficient MP), but was decreased in the mid-lactation diets (see Scenario 2).

A cogent comparison can be made between a diet containing an untreated alfalfa silage, and a diet containing a treated alfalfa silage with a final NDF level equal to that of the untreated silage in the first diet. For example, consider a diet with untreated 51% NDF silage and another diet with 57% NDF silage treated to yield a 6 percentage point reduction, both for the early-lactation cow group. In the first diet, alfalfa silage was 19% of the diet, and the diet cost was $2.71/d. In the second diet, about the same amount of alfalfa silage was used (20% of the diet), but less corn silage, more corn grain, less SBM, and more heat-treated SBM were used. The net effect was a diet cost of $2.75/d. Thus, the diet containing treated silage was more expensive than one containing untreated silage, both with the same NDF level. Similar results were obtained for other comparisons between equal-NDF treated and untreated silages. At the same NDF level, enzyme-treated silage had a higher lignin content and therefore yielded less ME than untreated silage. Other aspects of treated and untreated silages not considered in this scenario, such as NSC concentration, NSC composition, and rate of fiber digestion, are also likely to be different in practical situations. Thus, enzyme treated silage was not equivalent to an untreated silage with the same NDF level. This suggests that enzyme treatment is not a substitute for proper maturity management of alfalfa.

Scenario 2: Increased milk production

Tables 5 and 6 show the predicted effects on digestion and milk production of using the initial diets of Tables 2 and 3 with various levels of NDF reduction. Starting with an initial diet that was balanced, reductions in NDF with no change in diet had the following effects. First, the rate of passage (K_p) of the alfalfa silage increased. The ME from the alfalfa silage and from the whole diet increased. The predicted yield of NSC-fermenting bacteria increased while the yield of SC-fermenting bacteria decreased. Total bacterial yield from the alfalfa silage stayed approximately constant for the early-lactation group (Table 5) and increased slightly for the mid-lactation group (Table 6). Model-predicted ruminal degradation of NSC increased with NDF reduction, but degradation of SC decreased owing to the greater proportion of lignin within the SC of enzyme-treated silage as well as the higher passage rate (increased K_p).

For the early-lactation group (Table 5), the MP balance became increasingly negative as NDF was reduced. A negative MP balance indicates insufficient protein is being provided to the animal as the feed passes through the lower tract. The MP is provided from the combination of microbial protein from ruminal microorganisms and from feed protein which bypasses the rumen. With enzyme treatment, the rate of passage through the rumen (K_p) was increased for the alfalfa silage (Table 5) and, therefore, for the whole diet. Although microbial yields for the alfalfa silage were roughly constant, the higher rate of passage allowed less time for microbial growth, and this lowered the microbial yield from the remainder of the diet. With lower microbial levels, the MP supplied by the diet decreased. This decrease in MP was offset by the use of more heat-treated SBM in the rebalanced diets for early-lactation cows in Scenario 1.

For the mid-lactation cows (Table 6), a slightly different effect on MP was seen. In this case, the MP balance became increasingly positive as NDF was released, despite increases in K_p similar to those for the early-lactation group. The 51% NDF silage had a lower K_p and a longer retention time in the rumen than the 46% NDF silage. This longer retention time allowed higher bacterial yields from the alfalfa silage in the conversion of SC to NSC caused by enzyme treatment. Combined with a higher amount of alfalfa silage in the diet for the mid-lactation group, the overall effect was an increase in MP from the diet. In Scenario 1, this increase in MP allowed the removal of heat-treated SBM in the rebalanced diets for mid-lactation cows.

The increases in ME-allowed milk production are shown in Tables 5 and 6. With a 4 percentage point reduction in NDF, milk production was increased by about 0.4 lb/d for both cow groups. This translated to substantial economic value for the enzyme treatment, much more than for rebalanced diets with no production response (Scenario 1). The economic value, however, depended on milk price, with a higher milk price giving a more favorable return from enzyme treatment. For example, an economic value of $3.50/ton silage required a 4 percentage point reduction in NDF with a $14/cwt milk price, and a 6 percentage point reduction with a $10/cwt milk price.

Similar economic values were found for the other alfalfa silages (Table 4). Again, enzyme treatment was most valuable for the 46% NDF silage with the early-lactation cow group. Lowest economic values for treatment were attained with the lowest initial NDF (early bloom) alfalfa.

Scenario 3: Increased DMI and milk production

In this scenario, DMI was increased with enzyme treatment to maintain a constant intake of eNDF, and the ME-allowed increase in milk production was calculated. Tables 7 and 8 show the projected results for the early- and mid-lactation groups, respectively. With a 4 percentage point reduction in NDF, DMI for the early-lactation group was increased by 1.6 lb/d, resulting in substantial excesses of ME and MP in the diet. For example, the ME balance without increased DMI (Scenario 2) was increased by 0.2 Mcal/d with a 4 percentage point reduction in NDF (Table 5), and by 1.9 Mcal/d when DMI was increased (Table 7). Thus, the milk production response was much greater than in Scenario 2 (e.g., 3.95 lb/d vs. 0.40 lb/d with a 4 percentage point reduction). The value of the treatment in terms of extra milk, subtracting the extra diet cost, was almost 10 times larger than with no increase in DMI. With even small (2 percentage point) reductions in NDF, the treatment value was $12 to $19/ton silage, which would exceed the cost of any known enzyme additive by several times. Results for the mid-lactation group (Table 8) showed a production response and treatment value that were about 70% of those for the early-lactation group.

Table 9. Effect of reducing NDF, increasing DMI, and increasing the digestion coefficient K_d of the available fiber fraction in the alfalfa silage on milk production for the early-lactation cow group (Scenario 3). Original diet as in column 1, Table 2. Adjusted treatment values are for a 1/3 increase in projected milk production.

	NDF of alfalfa silage, % DM			
	Untreated 46	44	42	40
DMI, lb/d	47.71	48.47	49.29	50.12
ME balance, Mcal/d	3.4	4.5	5.5	6.6
MP balance, lb/d	0.0	0.0881	0.1696	0.2511
Predicted increase in milk production, lb/d	0.0	2.08	4.10	6.17
Treatment value, $/ton silage				
$10/cwt milk	--	17.26	26.30	49.61
$12/cwt milk	--	20.71	33.01	59.54
$14/cwt milk	--	24.16	39.71	69.46
Adjusted treatment value, $/ton silage				
$10/cwt milk	--	5.75	8.77	16.54
$12/cwt milk	--	6.90	11.00	19.85
$14/cwt milk	--	8.05	13.24	23.15

As for the previous scenarios, the treatment values were greatest for 46% NDF silage for the early-lactation cow group (Table 4). Even though the lowest value was achieved with the early bloom silage (42% NDF), in this scenario the treatment values were still extremely high ($10.33/ton silage with a 2 percentage point reduction, $10/cwt milk price, and the early-lactation group).

Finally, an increase in the digestion coefficient (K_d) of the available fiber fraction from 7 to 9%/h produced an even greater ME excess, MP excess, milk production increase, and treatment value. As shown for the early-lactation group (Table 9), DMI was unchanged by increasing K_d, because the rate of passage (K_p) was not changed. Because more fiber was digested in the rumen, however, more bacterial protein was extracted from the available fiber fraction (higher ME). Milk production increases and treatment values were about 10% higher than with constant K_d (Table 7).

The predicted animal response associated with a 6 percentage point reduction in NDF was an increase of about 5 and 7.5% of the base DMI and milk production, respectively, for the early-lactation group. The data of Stokes (1992) showed increases of 9.6 and 2.4% in base DMI and milk production, respectively. Thus the predicted increase in DMI was lower than in Stokes (1992) but the predicted increase in milk production was higher. On the other hand, Stokes (1992) also observed a change in weight gain with enzyme-treated silage, and thus a fraction of the increased ME obtained from the diet actually was allocated to body condition and not all to milk production. The economic returns from milk production in Scenario 3 may therefore be high by a factor of about 3. Tables 7, 8, and 9 show the treatment values adjusted for only a 1/3 increase in projected milk production. Adjusted treatment values were substantial but still may not exceed treatment costs with only a 2 percentage point reduction in NDF. Thus, both a production response and a minimum 4 percentage point decrease in NDF are predicted to be required for significant economic returns of enzyme treatment. In view of the variable results obtained by different researchers, the economic return of enzyme treatment would also be expected to vary.

ACKNOWLEDGMENT

This work was performed as part of the Northeast Regional Research Project NE-132.

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