

Effect of Formic Acid or Formaldehyde Treatment of Alfalfa Silage on Nutrient Utilization by Dairy Cows¹

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ABSTRACT

Third-cutting alfalfa with 37% DM was ensiled untreated or treated with either 2.8 g of formic acid/100 g of DM or .31 g of formaldehyde/100 g of DM and fed to lactating dairy cows in two experiments. Silage treated with formic acid had the lowest pH and concentrations of NPN, NH₃, and total free AA. Both treatments decreased rumen *in vitro* protein degradability but did not affect *in vitro* rumen plus pepsin digestibility. In trial 1, part 1, 22 Holstein cows received a standard diet for 18 d postpartum and then were fed for 6 wk one of three diets containing 98% alfalfa silage DM. Although DMI was comparable, yields of milk, SCM, fat, protein, lactose, and SNF were higher when treated silages were fed. Plasma concentrations of branched-chain, essential, and total AA increased when formic acid-treated silage was fed. Rumen pH and concentrations of NH₃ and VFA were similar for all diets. Rumen escape protein, estimated using ¹⁵N as a microbial protein marker, was increased more by formic acid than by formaldehyde treatment. In trial 1, part 2, supplementation with 4.8% fish meal increased concentration of milk protein and yields of milk, protein, lactose, and SNF. Milk urea concentration

was higher on the untreated silage diet. Total tract apparent DM and N digestibilities were not affected by silage treatment, although fish meal decreased apparent DM digestibility. In trial 2, 80:20 alfalfa silage:ground corn diets were fed to 12 midlactation cows in a 3 × 3 Latin square study. Milk production was unaffected, but milk protein concentration and DMI were higher when treated silages were fed. Feeding treated silages increased plasma concentrations of branched-chain AA, essential AA, and total AA. Formaldehyde and especially formic acid treatment effectively improved utilization of nutrients in alfalfa silage by lactating dairy cows.

(Key words: alfalfa silage preservation, formic acid, formaldehyde, protein utilization)

Abbreviation key: AP = absorbed protein, BCAA = branched-chain AA, BCAA:Gly = BCAA:glycine ratio, EAA = essential amino acids, GLM = general linear models, IADF = indigestible ADF, UIP = undegraded intake protein.

INTRODUCTION

Alfalfa protein is subject to extensive degradation during ensiling; as much as 75 to 87% of the total N present in alfalfa silage may be NPN (23). This results in inefficient N use, especially in diets in which fermentable energy is limiting. Formic acid commonly is used as a preservative for direct-cut silage in northern Europe. Formic acid-treated alfalfa silage had lower pH and NH₃ concentrations than untreated controls and increased water-insoluble N (3, 20). Formic acid was more consistent than bacterial inoculants in reducing protein degradation and deamination in clover silage

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(37). Increased DMI and N retention have been reported in sheep (3) and dairy heifers (34) fed treated alfalfa silage. Little information is available on milk production when formic acid-treated alfalfa is fed to dairy cattle. Glenn et al. (15) reported a trend for higher milk yields when cows were fed alfalfa silage treated with formic acid plus formaldehyde; however, alfalfa comprised only 30% of the diet DM.

Formaldehyde reduces protein degradability by forming crosslinks between protein chains and has antimicrobial properties that may alter the bacterial population and fermentation pattern of silage (36). Formaldehyde treatment of direct-cut herbage decreased proteolysis and apparent N digestibility (3), although it increased N retention in growing sheep (3). Little is known about the effect of feeding lactating cows formaldehyde-treated alfalfa silage. Formaldehyde is presently approved for use as an antifungal agent in silages (W. A. Olson, personal communication). Residual formaldehyde levels in milk from cows fed formaldehyde-treated grass silages have been found to be negligible (18, 32).

The objectives of this study were to test the effects of treating wilted alfalfa silage with formic acid or Grainmax™, a formaldehyde-based product, on DMI, milk and milk component yield, plasma metabolite concentrations, and DM and N digestion in lactating dairy cattle. In addition, the effects of these chemicals on silage fermentation and protein degradation in the silo and rumen were determined.

MATERIALS AND METHODS

Alfalfa was grown at the US Dairy Forage Research Center Farm, Prairie du Sac, WI. Third-cutting, midbloom alfalfa was allowed to wilt to approximately 35% DM and then was ensiled in three polyethylene bag silos. Forage was ensiled untreated (control, treatment C), or treated at the harvester blower with (per ton of wet silage) 8.2 L of 90% (wt/wt) formic acid (treatment F) solution (Hydrite Chemical Company, Cottage Grove, WI) or 6.3 L of Grainmax™ (treatment G) solution (Farnos, Upper Montclair, NJ). Grainmax™ had a pH of 1.9 and contained 16% (wt/vol) formaldehyde as determined by the method of Bricker and Johnson (5). Treatments were applied to alter-

nate loads of chopped herbage. The amount of formic acid required to titrate herbage samples to pH 4.0 was used to determine formic acid application rate; Grainmax™ was applied as per the manufacturer's directions. Application rates were 2.8 g of formic acid/100 g of DM or .31 g of formaldehyde/100 g of DM (1.3 g of formaldehyde/100 g of CP). Samples of herbage were taken from each wagon load and stored at -20°C.

Trial 1

Twenty-two multiparous Holstein cows, including 4 with rumen cannulas, were fed a covariate diet from d 4 to 18 postcalving and then randomly assigned to one of three alfalfa-based diets on d 19. There were 2 ruminally cannulated cows in each group, including 2 midlactation cows (1 assigned to diet F and 1 to diet G). Thus, 8 cows were offered each diet. Ketoban™ (Osborn Corp., Fort Dodge, IA) was added to diets in trial 1 to prevent off-feed and ketosis problems associated with the change from the higher energy covariate diet to the all-forage diet. During part 1 of trial 1 (d 19 to 60 postpartum), cows were fed, without change, diets of essentially all alfalfa silage. During part 2 of trial 1 (d 61 to 88 postpartum), cows were used in a 28-d switchback study consisting of two, 14-d periods. Half of each treatment group continued on the same silage diet fed during period 1; the other half received the same silage plus fish meal (Zapata Haynie Corp., Hammond, LA). Diets were switched during period 2. Diet compositions are in Table 1.

Animals were housed in tie stalls, and diets were offered for ad libitum intake once daily as TMR. Orts were weighed once daily. Silages and Orts were sampled daily, stored frozen, and composited weekly for DM analysis (60°C for 48 h). Diets were adjusted weekly for variations in DM content of the diet components based on 60°C DM. Animals were milked twice daily; milk samples were obtained weekly from each cow from four consecutive milkings and composited proportionally for determination of fat, protein, lactose, and SNF by infrared analysis (Wisconsin DHI Cooperative, Madison, WI). Composites were deproteinized using TCA, and supernatants were stored at -20°C until analyzed for urea

TABLE 1. Composition of diets.

Item	Covariate	Trial 1 ¹		Trial 2
		Part 1	Part 2	
		(% of DM)		
Alfalfa silage	48.1	...	...	...
Ground corn	34.3	...	...	18.80
Soybean meal	15.7	...	...	...
Experimental alfalfa silage ²	...	98.38	93.63	79.90
Fish meal ³	...	...	4.75	...
Dicalcium phosphate	1.1	.70	.70	.70
Trace-mineral salt ⁴	.7	.70	.70	.50
Ketoban TM ⁵	...	.12	.12	...
Vitamin premix ⁶	.1	.10	.10	.10

¹No FM = Unsupplemented diet; FM = fish meal-supplemented diet.

²Experimental alfalfa silage was either untreated, formic acid-treated, or formaldehyde-treated.

³Fish meal contained 62% CP (DM basis).

⁴Contained (mg/kg of DM): Mn, 27; Zn, 27; Fe, 17; Cu, 7; I, .40; Se, .30; and Co, .10.

⁵Contains sodium choline, propylene glycol, cobalt sulfate heptahydrate, sodium saccharin, and sorbitol (Osborn Corp., Fort Dodge, IA).

⁶Contained 3530 IU of vitamin A, 660 IU of vitamin D, and .660 IU of vitamin E/kg of DM.

(6). A blood sample and fecal grab sample were collected from each animal 4 h postfeeding at an average of 35, 72, and 96 d postpartum. Blood was sampled from coccygeal vein or artery into heparinized tubes, and plasma was recovered after centrifugation at $1500 \times g$ for 10 min. Feces and plasma were stored at -20°C .

Herbage and silage samples were thawed, then extracted with distilled water, and pH was measured (23). Extract (20 ml) was deproteinized using 5 ml of 25% (wt/vol) TCA. Water extracts were analyzed for lactate, acetate, ethanol, 2,3-butanediol, succinate, formate, propionate, and butyrate by HPLC (24). The TCA extracts were analyzed for NH_3 and total free AA (7) and NPN (23).

Dry feeds were ground through a 1-mm Wiley mill screen (Arthur H. Thomas, Philadelphia, PA); samples of both silage and dry feeds from 3 or 4 wk were composited for subsequent analysis. Composites were analyzed for total N by Kjeldahl (1) using a copper catalyst (Kjeltabs, Tecator Inc., Herndon, VA) during the digestion, NDF (29), ADF without decahydronaphthalene and ADIN (16), indigestible ADF (IADF) (14), and in vitro ruminal and total N digestibility (2). Feces were dried at 60°C for 48 h and ground through a 1-mm Wiley mill screen and ana-

lyzed for DM, IADF, and total N. Total tract apparent DM and N digestibilities were calculated using IADF as an internal marker (11). Plasma was deproteinized using 4 vol of plasma:1 vol of 15% (wt/vol) 5-sulfosalicylic acid and analyzed for glucose and urea (6) and for individual free AA using a Beckman 6300 amino acid analyzer (Spinco Division, Beckman Instruments, Palo Alto, CA).

At an average of 35 and 55 d after beginning trial 1, part 1, cannulated cows were pulse-dosed into the rumen with a solution containing $1.5 (\pm .15)$ g of $\text{YbCl}_3 \cdot 6\text{H}_2\text{O}$ to give about 30 ppm of Yb in rumen DM and with 2 g of 72 atom percentage excess $^{15}\text{N}[(\text{NH}_4)_2\text{SO}_4]$ (US Department of Energy, Mound Facility, Miamisburg, OH). The Yb administered in this way preferentially marks the small particle pool rapidly leaving the rumen (12). Rumen fluid was obtained by squeezing ventral rumen contents through two layers of cheesecloth at 0, 2, 4, 6, 9, 12, 15, 18, 21, and 24 h postfeeding; pH was measured. Fluid was acidified immediately by adding 1 ml of 50% (vol/vol) H_2SO_4 /50 ml of rumen fluid and stored at -20°C until analyzed. Digesta samples were obtained from the reticulo-omasal orifice at the same sampling times using a 22-mm i.d. tube attached to a vacuum pump. Samples taken from the

reticulo-omasal orifice should reflect material leaving the rumen. Half of the sample was preserved (5 ml of formalin/200 ml of sample), and half was stored at -20°C . Bacteria were harvested from the preserved sample by centrifugation (13). Microbial pellets were dried at 60°C .

Acidified rumen fluid samples were thawed and analyzed for NH_3 and total free AA (7) and VFA (31). Rumen fluid (15 ml) was treated with an equal volume of 13N NaOH and steam-distilled into 10 ml of .03N H_2SO_4 to collect NH_3 . Distillate was treated with 1 ml of 40% (wt/vol) aqueous KMnO_4 to avoid interference from methylamine. Digesta samples stored frozen were lyophilized and ground through a 1-mm Wiley mill screen. Digesta and bacteria samples were incubated with 3 ml of saturated K_2CO_3 solution at 37°C for 90 min to remove NH_3 and then analyzed for total N by Kjeldahl digestion. Kjeldahl digest (15 ml) was treated with 15 ml of 13N NaOH and steam-distilled as described for rumen NH_3 . Atom percentage of excess ^{15}N in rumen NH_3 N, digesta NAN, and bacterial NAN was determined using isotope ratio mass spectrometry (Varian MAT Mass Spectrometer, Flozham Park, NJ) with O_2 -free air as the standard. The proportion of total NAN (PNAN) present as bacterial NAN was calculated using the bacterial and digesta ^{15}N enrichments at each time point according to the relationship:

$$\text{PNAN} = \frac{(\text{atom percentage excess } ^{15}\text{N})_{\text{digesta}}}{(\text{atom percentage excess } ^{15}\text{N})_{\text{bacteria}}}$$

Dried reticulo-omasal digesta samples (1 g) were combusted at 500°C for 16 h and the ash dissolved using 15 ml of aqua regia solution (concentrated HCl:concentrated HNO_3 , 3:1, vol/vol). Samples were diluted to 100 g using .6% (wt/vol) LiOH solution. Another portion of omasal sample was thawed and centrifuged at $30,000 \times g$ for 20 min to separate the solid and liquid fractions. The pellet was washed once with distilled water. The supernatant plus wash was treated with LiCl to give 1000 ppm of Li. The pellet was dry ashed and diluted as described previously. The Yb concentration was determined in whole digesta, solids, and fluid by direct current plasma spectroscopy (SpectraMetrics, Inc., Andover, MA). Fractional passage rates of solids were estimated from the slope of the Yb concentration in

whole digesta samples after logarithmic transformation. Rumen DM mass was estimated using the Yb dose and the Y-intercept. The amount of Yb found in the fluid averaged 7.8% of that found in the solids portion. No correction was made for Yb in fluid when fractional passage rates of solids were calculated. Total NAN flow (grams per day) was calculated by multiplying DMI (grams per day), ruminal solids passage rate (per hour), average fraction NAN in reticulo-omasal digesta over the 24-h sampling period, and 24 (hours per day).

Trial 2

Twelve multiparous Holstein cows were blocked according to days in milk and production and used in a 3×3 Latin square design experiment with 2-wk periods. Protein yield response to postruminal protein infusion is very rapid, occurring within 24 h (8); hence, 1 wk was considered adequate for adaptation to the protein effects of the silages. These midlactation animals had been used in trial 1. Three diets using the previously described silages and ground corn were fed (Table 1). Determination of DMI, milk production, and milk sampling procedures were as described for trial 1. These data were collected during the 2nd wk of each period and used for statistical analysis. Blood was taken from the coccygeal vein or artery on the last day of each period, and plasma was prepared, deproteinized, and stored at -20°C until analyzed as described for trial 1.

Statistical Analysis

Production of milk and milk components during trial 1, part 1, was analyzed using the general linear models (GLM) of SAS (30) according to the model

$$Y_{ij} = m + T_i + b(X_{ij}) + E_{ij}$$

where Y_{ij} = the dependent variable for treatment i for cow j ; m = the overall mean; T_i = effect of treatment i , $i = \text{C, F, or G}$; b = the regression of Y on X ; X_{ij} = dependent variable for treatment i for cow j for the covariate period, $j = 1$ to 8 for C, $j = 1$ to 7 for F and G; and E_{ij} = random residual, assumed independent and normally distributed. Mean daily production of milk and milk components were regressed on daily milk production during the last 7 d of the covariate period. Dry matter

intake, milk component concentration, and plasma AA concentrations were analyzed using this model without the $b(X_{ij})$ term. Data from the two midlactation cows were not included in these analyses. Differences among diets for production data were separated by preplanned orthogonal contrasts. Single degree of freedom comparisons were A = untreated silage versus treated silage, and B = formic acid-treated silage versus formaldehyde-treated silage. Analysis of rumen pH, NH_3 , VFA, microbial N, NAN flow, and estimated escape N was done using the GLM of SAS (30) according to the model

$$Y_{ijk} = m + T_i + P_{ij} + E_{ijk}$$

where Y_{ijk} = dependent variable for treatment i and cow j ; m = the overall mean; T_i = effect of treatment i , $i = C, F, \text{ or } G$; P_{ij} = effect of treatment i for cow j , $j = 1 \text{ to } 2$ (error term used to test treatment effect); and E_{ijk} = random residual. Differences among diets were separated by preplanned orthogonal contrasts. Single degree of freedom comparisons were A = untreated silage versus treated silage, and B = formic acid-treated silage versus formaldehyde-treated silage.

Data obtained during trial 1, part 2, were analyzed using the GLM of SAS (30) according to the model

$$Y_{ijkl} = m + T_i + P_{ik} + X_j + (TX)_{ij} + F_l + (TF)_{il} + (XF)_{jl} + (TXF)_{ijl} + E_{ijkl}$$

where Y_{ijkl} = dependent variable for treatment i , sequence j , cow k , and fish meal level l ; m = the overall mean; T_i = effect of treatment i , $i = C, F, \text{ or } G$; P_{ik} = effect of treatment i for cow k , $k = 1 \text{ to } 8$ for C, $k = 1 \text{ to } 7$ for F and G (error term used to test treatment effect); X_j = effect of sequence j , $j = 1$ for fish in first period, $j = 2$ for fish in second period; $(TX)_{ij}$ = interaction of treatment i and sequence j ; F_l = effect of fish meal level, $l = 0 \text{ or } 1$; $(TF)_{il}$ = interaction of treatment i and fish meal level l ; $(XF)_{jl}$ = interaction of sequence j and fish meal level l ; $(TXF)_{ijl}$ = interaction of treatment i , sequence j , and fish meal level l ; and E_{ijkl} = random residual, assumed independent and normally distributed. When interaction terms were not significant, they were pooled with the residual

term. Differences among diets were separated using orthogonal contrasts. Single degree of freedom comparisons were A = untreated silage versus treated silage diets; B = formic acid-treated silage versus formaldehyde-treated silage diet; and C = no fish meal supplement versus fish meal supplement.

Milk production data, DMI, and plasma AA concentrations in trial 2 were analyzed using the GLM of SAS (30) according to the model

$$Y_{ijkl} = m + G_i + X_{ij} + P_{ik} + T_l + (GT)_{il} + E_{ijkl}$$

where Y_{ijkl} = the dependent variable for square i , period j , cow k , and treatment l ; m = the overall mean; G_i = effect of square i , $i = 1 \text{ to } 4$; X_{ij} = effect of period j for square i , $j = 1 \text{ to } 3$; P_{ik} = effect of square i for cow k , $k = 1 \text{ to } 3$; T_l = effect of treatment l , $l = \text{diet } C, F, \text{ or } G$; $(GT)_{il}$ = interaction of square i and treatment l ; and E_{ijkl} = random residual, assumed independent and normally distributed. When interaction terms were not significant, they were pooled with the residual term. Treatment differences were separated using preplanned, single degree of freedom orthogonal comparisons, which were A = untreated silage versus treated silage and B = formic acid-treated silage versus formaldehyde-treated silage. Significance was declared at $P < .05$ unless otherwise noted.

RESULTS

Trial 1

A summary of changes in the N fractions of treated herbage and silages is in Table 2. Formic acid was more effective in reducing herbage pH than was formaldehyde. Total N was slightly less in silage than herbage, whereas NPN rose substantially. Free AA N and NH_3 increased during fermentation, but this effect was less apparent for F silage.

Treatment had little effect on silage DM, NDF, ADF, or ADIN (Table 3). Total organic acids were considerably lower for F than C or G, indicating that fermentation was restricted. The NPN, NH_3 , and free AA concentrations were lowest in F silage, followed by G, then C. Untreated silage contained the highest concentration of butyric acid, although all silages

TABLE 2. Effect of chemical treatment¹ and fermentation on herbage composition.

Item	Herbage				Silage			
	C	F	G	SE	C	F	G	SE
No. samples	11	10	10		15	14	14	
DM, %	36.7	32.6	34.1	2.1	38.3	35.2	35.9	1.8
pH	5.98	4.27	5.60	.05	4.48	4.27	4.43	.04
Total N, % DM	3.62	3.74	3.78	.09	3.43	3.31	3.38	.07
	(% TN)							
NPN	17.0	15.3	15.3	1.3	43.1	29.1	35.5	1.2
NH ₃ N	.41	.22	.49	.29	6.39	1.23	4.30	.24
Free AA N	5.2	4.7	4.5	1.1	31.2	14.4	25.0	.9

¹C = Untreated; F = formic acid-treated; G = formaldehyde-treated; TN = total N. Values are least squares means.

had low levels. In vitro degradability of silage N in rumen fluid was less for treated silages than for C (Table 3). Similar extents of N digestion were found when rumen fluid was followed by a pepsin digestion.

Data on DMI, BW change, and milk production for trial 1, part 1, are in Table 4. Dry

matter intake and BW loss were similar for all diets. Covariate adjusted milk production and SCM were higher for treated silage diets than for C. Concentration of milk fat was lower and urea higher for C than for treated silage diets. Milk protein concentration was higher when F rather than G silage was fed. This also was

TABLE 3. Chemical composition and in vitro N digestibility of alfalfa silages.

Item	Silage ¹			SE ²
	C	F	G	
DM, %	38.3	35.2	35.9	1.8
pH	4.48	4.27	4.43	.04
NDF, % DM	38.9	41.2	41.3	1.2
ADF, % DM	32.7	29.8	31.9	1.1
Total N (TN), % DM	3.43	3.31	3.38	.11
ADIN, % TN	5.6	4.9	5.3	.4
NPN, % TN	43.1	29.1	35.5	1.4
NH ₃ , % TN	6.4	1.2	4.3	.3
Free AA, % TN	31.2	14.4	25.0	1.3
Organic acids, % DM				
Succinic	.35	.15	.24	.02
Lactic	4.93	1.34	5.32	.33
Acetic	2.84	.56	1.85	.26
Propionic	.01	0	0	.01
Butyric	.13	.06	.10	.01
Formic	.29	1.85	.32	.07
Total ³	8.55	3.96	7.84	.48
Butanediol	.28	.17	.22	.02
Ethanol	.14	.02	.10	.02
In vitro N digestibility	(% TN digested)			
Rumen fluid	52.2	41.7	46.5	1.8
Rumen fluid plus pepsin	75.9	76.5	75.7	1.2

¹C = Untreated; F = formic acid-treated; G = formaldehyde-treated.

²SE = Standard error of least squares mean (n = 5 per mean for total N, NDF, ADF, ADIN; 12 per mean for N digestibility; 10 per mean for organic acids and alcohols; 14 per mean for other variables).

³Sum of succinic, lactic, acetic, propionic, butyric, and formic acids.

TABLE 4. Effect of diet on DMI, BW change, production of milk and milk components, and milk urea concentration in trial 1, part 1.

Item	Diet ¹			SE	Contrasts ²
	C	F	G		
Cows, n	8	7	7		
DMI, kg/d	18.3	18.2	19.7	1.1	
BW Change, kg/d	-.19	-.26	-.52	.29	
Milk, ³ kg/d	29.2	32.6	32.5	.9	A*
SCM, kg/d	27.3	31.2	31.0	1.2	A*
Fat, ³ %	3.71	4.06	4.03	.12	A*
Fat, ³ kg/d	1.10	1.30	1.30	.05	A*
Protein, ³ %	2.74	2.90	2.68	.08	B*
Protein, ³ kg/d	.81	.92	.87	.03	A*
Lactose, %	4.85	4.89	4.87	.06	
Lactose, ³ kg/d	1.45	1.56	1.58	.05	A*
SNF, %	8.21	8.41	8.16	.09	B†
SNF, ³ kg/d	2.45	2.69	2.65	.08	A*
Urea, mM	6.85	5.96	6.26	.28	A*

¹C = Untreated; F = formic acid-treated; G = formaldehyde-treated. Values are least squares means.

²Single degree of freedom orthogonal contrasts: A = untreated versus treated, B = formic versus formaldehyde.

³Covariate adjusted.

† $P < .10$.

* $P < .05$.

reflected in a trend for higher ($P < .1$) SNF concentration. Covariate-adjusted fat, protein, lactose, and SNF production were greater on treated silage diets than on C.

Rumen pH, total VFA concentration, and acetate:propionate ratios were comparable across diets (Table 5). Ammonia concentration tended to be lower ($P < .1$) when treated silages were fed. Molar proportions of isobutyrate and isovalerate plus 2-methylbutyrate were higher on G than on F; but acetate, propionate, butyrate, and valerate were not different ($P > .25$). Microbial N was a greater proportion of rumen NAN in cows fed C than in cows fed treated silage and tended to be greater ($P < .1$) for G than F (Table 6). Passage of bacterial N and total NAN was similar among diets. Dietary NAN flow was lower for untreated silage. Estimated rumen escape of dietary NAN tended to be higher ($P < .1$) for F than for G.

Concentrations of plasma metabolites in trial 1, part 1, are in Table 7. Urea and glucose were not affected by diet. Hydroxyproline, threonine, valine, isoleucine, and leucine concentrations were higher when treated silages were fed, whereas glutamine and methionine were lower. Diet F increased plasma threonine,

valine, cystine, leucine, ornithine, and lysine when compared with diet G. Branched-chain AA (BCAA), BCAA to glycine ratio (BCAA:Gly), and essential AA (EAA) concentrations were higher for treated silages when compared with the control and were higher for diet F than G. Sulfur-containing AA were higher for C than treated and were higher for F than G diet. Total AA also were higher for diet F than for G.

Dry matter intake and milk production with fish meal supplementation of silages (trial 1, part 2) are in Table 8. No treatment by fish meal interactions were significant for any production parameters ($P > .10$). A sequence by fish meal interaction was found in milk urea concentration. Fish meal feeding increased milk urea concentration, milk production, protein concentration, and protein, lactose, and SNF secretion. Untreated silage diets resulted in lower fat concentration and yield than treated silage diets. Total tract apparent DM digestibility was decreased by fish meal supplementation, although apparent N digestibility was unaffected (Table 8).

Plasma urea was increased by fish meal supplementation, but glucose was unaffected (Table 9). Plasma concentrations of alanine,

TABLE 5. Effect of diet on rumen pH, NH₃ and total VFA concentrations, and molar proportions of VFA.

Item	Diet ¹			SE	Contrasts ²
	C	F	G		
pH	6.38	6.54	6.45	.19	
NH ₃ , mM	17.4	10.8	13.2	1.6	A [†]
Total VFA, mM	129.9	122.6	122.9	6.5	
VFA, mol/100 mol					
Acetate (A)	66.4	68.0	66.1	1.5	
Propionate (P)	18.3	18.0	18.7	.8	
Isobutyrate	1.3	1.2	1.8	.1	B [†]
Butyrate	10.5	10.0	10.3	.6	
Isovalerate plus 2-methylbutyrate	1.8	1.2	1.6	.1	A*, B [†]
Valerate	1.7	1.6	1.6	.1	
A:P	3.63	3.78	3.53	.20	

¹C = Untreated; F = formic acid-treated; G = formaldehyde-treated. Values are least squares means (n = 2).

²Single degree of freedom orthogonal contrasts: A = untreated versus treated, B = formic acid versus formaldehyde.

[†]P < .10.

*P < .05.

leucine, histidine, arginine, and BCAA:Gly increased over time, which led to a sequence by fish meal interaction. Treated silage diets gave lower plasma serine, glutamine, and glycine but higher alanine, valine, isoleucine, and leucine concentrations than C. Plasma asparagine, glutamine, alanine, and tyrosine were lower for diet F than G, but valine, leucine, and isoleucine were higher. A treatment by fish meal interaction was detected for plasma histidine, because concentration decreased with supplementation for diet C, but it increased for diets

F and G. Branched-chain AA, BCAA:Gly, and EAA were higher for treated silage diets than C diets, but nonessential AA were lower. The same results were found for F versus G.

Trial 2

Dry matter intake and BW gain on treated silage diets were higher than those on C (Table 10). Protein concentration and yield also were increased. Milk production, SCM production, and fat and lactose concentrations were unaf-

TABLE 6. Solid passage rate, proportion of microbial NAN in reticulo-omasal digesta, daily flow from the rumen of dietary NAN, and estimated rumen escape of dietary N.

Item	Diet ¹			SE	Contrasts ²
	C	F	G		
Solid passage rate, ³ /h	.07	.10	.05	<.01	
Microbial N, % NAN	65	47	55	3	A*, B [†]
NAN Flow, g/d	528	559	541	65	
Microbial NAN, g/d	343	253	298	35	
Dietary NAN, g/d	185	306	243	35	A*
Estimated escape N, % Total N	30	55	34	9	B [†]

¹C = Untreated; F = formic acid-treated; G = formaldehyde-treated. Values are least squares means (n = 2).

²Single degree of freedom orthogonal contrasts: A = untreated versus treated, B = formic acid versus formaldehyde.

³Ruminal solid passage rate determined from Yb dilution in whole digesta samples.

[†]P < .10.

*P < .05.

TABLE 7. Plasma urea (mM), glucose (mg/dl), and AA concentrations (nmol/ml) for trial 1, part 1.

Item	Diet ¹			SE	Contrasts ²
	C	F	G		
Urea	9.4	8.7	9.6	.6	
Glucose	67.8	60.6	65.0	3.8	
Hydroxyproline	55.8	84.2	79.7	8.1	A*
Threonine	85.4	130.5	98.5	8.3	A*, B*
Serine	81.7	77.0	63.7	8.4	
Asparagine	74.6	101.8	96.3	23.2	
Glutamic acid	153.5	157.1	145.9	8.5	
Glutamine	246.8	174.7	197.7	16.5	A*
Proline	65.3	80.9	69.4	4.3	A†
Glycine	381.8	326.5	350.7	46.5	
Alanine	158.0	166.5	150.3	17.9	
Citrulline	84.9	106.8	83.7	12.2	
Valine	281.2	519.3	343.8	35.4	A*, B*
Cystine	10.9	14.7	10.6	.7	A†, B*
Methionine	10.9	5.8	3.6	1.6	A*
Isoleucine	148.3	237.8	176.7	20.1	A*, B†
Leucine	140.2	268.5	185.0	20.1	A*, B*
Tyrosine	42.0	62.2	53.7	5.7	A†
Phenylalanine	47.5	59.1	51.4	3.3	
Tryptophan	12.9	19.9	18.2	3.7	
Ornithine	47.1	75.6	53.1	5.8	A†, B*
Lysine	82.7	116.6	80.2	8.6	B*
Histidine	51.0	57.9	51.6	2.7	
3-Methyl histidine	1.4	.5	.9	.7	
Arginine	80.2	83.8	64.3	7.0	B†
S-Containing AA ³	21.9	20.6	14.2	1.6	A*, B*
BCAA ⁴	570	1026	706	74	A*, B*
BCAA:Glycine	1.6	3.4	2.2	.3	A*, B*
EAA ⁵	940	1499	1073	92	A*, B*
NEAA ⁶	1162	1084	1074	55	
EAA plus NEAA	2101	2584	2147	122	A†, B*

¹C = Untreated; F = formic acid-treated; G = formaldehyde-treated. Values are least squares means (n = 6).

²Single degree of freedom orthogonal contrasts: A = untreated versus treated, B = formic versus formaldehyde.

³Sulfur-containing AA, sum of methionine plus cystine.

⁴Branched-chain AA, sum of valine, isoleucine plus leucine.

⁵Essential AA, sum of lysine, histidine, arginine, threonine, valine, methionine, isoleucine, leucine, tryptophan plus phenylalanine.

⁶Nonessential AA, sum of asparagine, serine, glutamic acid, glutamine, alanine, glycine plus proline.

†*P* < .10.

**P* < .05.

fed by diet (*P* > .20). Concentration of SNF tended to increase (*P* < .10) when treated silages were fed. Yields of fat, lactose, and SNF were not different.

Plasma glucose was lower when treated silages were fed (Table 11). Urea concentration was increased when treated silage was fed and was higher for F than G. Threonine, proline, citrulline, valine, isoleucine, leucine, tyrosine, phenylalanine, tryptophan, ornithine, ly-

sine, histidine, and arginine concentrations were lower, but glutamic acid, glutamine, and glycine were higher when untreated silage was fed. Glutamic acid and glycine decreased more for diet F than G, whereas valine, isoleucine, and leucine were higher. Branched-chain AA, BCAA:Gly, and EAA were higher on treated silage diets and on F versus G. Total protein AA were higher for treated silage diets versus C.

TABLE 8. Effect of diet on DMI, production of milk and milk components, milk urea concentration, and total tract DM and N digestibilities in trial 1, part 2.

Item	Diet ¹									Contrasts ²
	C			F			G			
	NoFM	FM	SE	NoFM	FM	SE	NoFM	FM	SE	
Cows	8	8		7	7		7	7		
DMI, kg/d	21.6	20.1	.7	21.3	21.9	.8	23.7	22.2	.8	
Milk, kg/d	28.5	29.7	.5	29.8	31.0	.5	29.9	31.3	.5	C*
SCM, kg/d	24.4	25.2	.6	27.1	27.9	.6	26.2	27.6	.6	C†
Fat, %	3.15	3.07	.11	3.54	3.44	.12	3.33	3.33	.12	A*
Fat, kg/d	.90	.91	.04	1.05	1.06	.04	.99	1.03	.04	A*
Protein, %	2.75	2.87	.02	2.90	2.92	.03	2.74	2.86	.03	C*
Protein, kg/d	.78	.85	.02	.85	.90	.02	.82	.90	.02	C*
Lactose, %	4.88	4.84	.02	4.94	4.89	.03	4.85	4.87	.03	
Lactose, kg/d	1.39	1.44	.03	1.47	1.52	.03	1.45	1.52	.03	C*
SNF, %	8.27	8.34	.04	8.47	8.45	.04	8.23	8.37	.04	C†
SNF, kg/d	2.36	2.47	.04	2.52	2.62	.05	2.47	2.62	.05	C*
Urea, ³ mM	8.17	8.84	.21	6.65	7.81	.23	7.45	7.99	.23	C*
Digestibility										
DM, %	60.4	57.0	.8	61.2	60.2	1.0	62.4	58.1	1.0	A†, C*
N, %	70.8	68.4	1.0	69.4	72.6	1.2	70.9	73.0	1.3	

¹C = Untreated; F = formic acid-treated; G = formaldehyde-treated; No FM = unsupplemented diet; FM = fish meal-supplemented diet.

²Single degree of freedom orthogonal contrasts: A = untreated versus treated, C = no fish meal versus fish meal supplementation.

³Sequence by fish meal interaction ($P < .05$).

† $P < .10$.

* $P < .05$.

DISCUSSION

Silages were well preserved, as indicated by low pH and butyric acid concentrations (Table 3) (21). Formic acid rapidly decreased herbage pH and restricted fermentation, as illustrated by the low levels of organic acids and alcohols in the F silage. About two-thirds of the formic acid applied was recovered in the silage. Both C and G silages had typical levels of lactic acid, but G had higher lactic:acetic acids and lower succinate and butanediol. Low butyric acid concentrations suggested that wilting inhibited clostridial growth (35).

Changes in the N fraction of silages were substantially affected by additives. Formic acid was most effective in preventing protein degradation, probably by rapidly decreasing pH and inhibiting plant proteases. Reduced protein degradation was demonstrated by the lower NPN, NH_3 , and total free AA in F silage versus C or G (Table 3) even though C and G reached pH conditions typical for alfalfa silage. Similar results have been reported (3,

20). Although applied at the level recommended by the manufacturer, acid content of Grainmax™ may have been insufficient to drop herbage pH enough to inactivate plant proteases during the time required for formaldehyde to react with proteins. Herbage contained more N than silage, whereas DM tended to increase in silages (Table 2). These changes imply a loss of water-soluble N from silage that may have accounted for the relatively low levels of NPN present in all three silages. Broderick et al. (9) reported that alfalfa ensiled with 30 to 55% DM contained 62 to 76% NPN; mean NPN in the present trial was 36% of total N. Concentrations of NDF, ADF, ADIN, and CP were typical of late vegetative alfalfa (27), demonstrating that the forage was of high quality (Table 3), despite its harvest at midbloom. Silage NE_L , calculated according to Mertens (22), virtually was identical among silages: 1.46, 1.41, and 1.41 Mcal/kg of DM for C, F, and G, respectively.

Silage DMI by dairy cattle did not differ among treatments when all forage or diets

TABLE 9. Plasma urea (mM), glucose (mg/dl), and AA concentrations (nmol/ml) for trial 1, part 2.

Item	Diet ¹						SE	Contrasts ²
	C		F		G			
	NoFM	FM	NoFM	FM	NoFM	FM		
Urea	11.2	11.4	9.5	10.9	10.1	11.2	.3	A [†] , C*
Glucose	78.4	77.0	76.2	77.4	74.0	73.2	2.1	
Hydroxyproline	50.0	47.3	45.2	46.3	51.2	42.2	4.5	
Threonine	116.0	116.0	111.9	96.2	119.5	106.5	6.1	B [†]
Serine	88.7	86.1	78.5	69.5	80.1	75.0	4.5	A*, C [†]
Asparagine	113.7	149.6	94.5	103.3	134.3	142.1	18.8	B*
Glutamic acid	134.1	120.4	114.3	108.4	131.4	114.3	7.6	A [†]
Glutamine	233.2	231.6	170.4	177.7	215.6	218.8	9.1	A*, B*
Proline	68.5	75.8	72.4	67.1	73.0	75.7	3.3	
Glycine	287.5	288.1	228.6	208.1	261.7	234.2	21.5	A*
Alanine ³	181.7	190.0	209.9	181.4	216.0	210.6	9.3	A*, B*
Citrulline	87.4	93.6	87.6	90.5	83.5	79.8	4.9	B [†]
Valine	265.0	296.8	412.4	387.5	302.7	271.8	23.3	A*, B*
Cystine	12.3	15.5	15.5	15.7	12.7	10.9	1.8	B [†]
Methionine	14.9	18.8	16.3	18.3	17.8	18.8	1.6	
Isoleucine	125.5	144.6	187.6	169.2	143.8	128.5	12.0	A*, B*
Leucine ³	134.3	147.3	216.2	201.3	163.0	142.7	14.1	A*, B*
Tyrosine	54.4	52.3	58.8	49.5	63.0	54.8	2.7	B*, C*
Phenylalanine	49.6	50.6	58.6	53.2	54.9	48.9	2.8	
Tryptophan	15.0	20.5	18.3	20.2	24.9	17.8	3.5	
Ornithine	63.6	69.7	70.7	66.3	70.8	68.8	4.4	
Lysine	89.5	105.0	98.1	91.5	89.8	101.3	6.1	
Histidine ^{3,4}	49.5	55.0	50.0	49.5	51.8	48.7	2.3	
3-Methyl histidine	1.1	2.2	8.2	1.2	.6	2.3	3.3	
Arginine ³	100.4	111.4	92.8	89.2	103.3	102.7	7.7	
S-Containing AA ⁵	27.2	34.3	31.8	34.0	30.6	29.7	2.9	
BCAA ⁶	525	589	816	758	610	543	49	A*, B*
BCAA:Glycine ³	2.0	2.2	3.7	3.7	2.4	2.4	.2	A*, B*
EAA ⁷	960	1066	1262	1176	1072	988	68	A*, B*
NEAA ⁸	1107	1142	969	916	1112	1071	44	A*, B*
EAA plus NEAA	2067	2208	2231	2092	2184	2059	104	

¹C = Untreated; F = formic acid-treated; G = formaldehyde-treated. Values are least squares means (n = 6).

²Single degree of freedom orthogonal contrasts: A = untreated versus treated, B = formic versus formaldehyde; C = no fish meal versus fish meal supplementation.

³Sequence by fish meal interaction ($P < .05$).

⁴Treatment by fish meal interaction ($P < .05$).

⁵Sulfur-containing AA, sum of methionine plus cystine.

⁶Branched-chain AA, sum of valine, isoleucine plus leucine.

⁷Essential AA, sum of lysine, histidine, arginine, threonine, valine, methionine, isoleucine, leucine, tryptophan plus phenylalanine.

⁸Nonessential AA, sum of asparagine, serine, glutamic acid, glutamine, alanine, glycine plus proline.

[†] $P < .10$.

* $P < .05$.

supplemented with fish meal were fed in trial 1 (Tables 4 and 8), but DMI was greater on diets containing treated silages when the corn-supplemented diets were fed in trial 2 (Table 10). Although DMI was similar in trial 1, part 1, cows fed F or G silage produced more milk, SCM, and milk components than those receiv-

ing silage C (Table 4). Intakes of NE_L were 27.6, 26.9, and 30.3 Mcal/d on diets C, F, and G, which met 90, 79, and 90% of the daily requirements (27) for maintenance and production. The apparent weight loss, which was confounded with DMI and increasing rumen fill (17), probably was less than the actual

TABLE 10. Effect of diet on DMI, BW change, and production of milk and milk components in trial 2.

Item	Diet ¹			SE	Contrasts ²
	C	F	G		
DMI, kg/d	19.6	23.2	21.8	.5	A*
BW Change, kg/d	-.38	.32	.55	.14	A*
Milk, kg/d	28.3	28.5	28.5	.2	
SCM, kg/d	25.4	25.8	25.4	.4	
Fat, %	3.35	3.37	3.28	.09	
Fat, kg/d	.95	.96	.93	.03	
Protein, %	2.90	2.97	2.94	.01	A*, B [†]
Protein, kg/d	.82	.84	.84	.01	A*
Lactose, %	5.00	4.98	5.00	.02	
Lactose, kg/d	1.42	1.42	1.43	.01	
SNF, %	8.55	8.60	8.59	.02	A [†]
SNF, kg/d	2.42	2.45	2.45	.02	

¹C = Untreated; F = formic acid-treated; G = formaldehyde-treated. Values are least squares means (n = 12).

²Single degree of freedom orthogonal contrasts: A = untreated versus treated, B = formic versus formaldehyde.

[†]P < .10.

*P < .05.

tissue mobilization. Efficiency of conversion of silage DM to milk, milk production per DMI, was 1.60 for C, 1.79 for F, and 1.65 for G. These values were comparable with efficiencies reported by Murphy and Gleeson (25) for grass silage. Although production was unaffected, midlactation cows in trial 2 ate more treated than untreated silage. Because periods were only 2 wk long, BW changes probably reflected intake differences rather than actual tissue gain or loss.

Absorbed protein (AP) needs were estimated by summing AP requirements for individual functions computed with the revised protein system of the NRC (27). Average BW over the course of trial 1, part 1, was used to compute maintenance AP. Average BW (kilograms) and AP requirement (grams of protein per day) for diets C, F, and G were 611 and 1852; 627 and 2005; and 608 and 1882, respectively. The supply of AP was calculated from NE_L values and protein undegradability values of 23, 48, and 27% for C, F, and G. These values were derived from estimated escape values in Table 6 by discounting each by 7 percentage units to normalize the protein escape for silage C to the NRC value of 23%. Supplies of AP were 1822, 2458, and 2098 g/d for diets C, F, and G; AP supply was similar to the requirement for C but over 450 and 220 g/d higher than the computed requirements for diets F and G, respectively. Protein status

clearly was better on silages F and G; AP supply may have limited production on silage C. Protein absorbed in excess of demand serves as a source of gluconeogenic precursors, which partly may explain the higher milk yields of cows fed silages F and G.

In trial 1, part 2, diets supplemented with fish meal supplied 121, 380, and 143 g/d of additional AP over unsupplemented diets C, F, and G, assuming a 60% undegraded intake protein (UIP) for fish meal (27). Supplementation increased daily milk yield 1.2 kg and protein secretion 50 to 80 g (Table 8). Fish meal feeding also increased lactose and SNF production because of higher milk yields. It was hypothesized that cows receiving C, the diet lowest in ruminal escape protein, would respond most favorably to increased escape protein. No fish meal by diet interaction was significant for any milk criterion, indicating that response to fish meal was independent of silage treatment. Response to supplementation may have been the result of changes in the amount and type of AA absorbed. Increased weight gain was observed by Barry et al. (3) when alfalfa-based diets were supplemented with DL-methionine. Fish meal protein contains higher S-containing AA and lysine than does alfalfa (26).

Concentration of most milk components was unaffected by silage treatment. Protein concentration was depressed in all treatments.

TABLE 11. Plasma urea (mM), glucose (mg/dl), and AA concentrations (nmol/ml) for trial 2.

Item	Diet ¹			SE	Contrasts ²
	C	F	G		
Urea	9.5	10.7	9.8	.2	A*, B*
Glucose	85.5	82.0	80.5	1.5	A*
Aspartic acid	7.4	7.8	8.2	.7	
Hydroxyproline	12.2	9.2	7.9	3.7	
Threonine	100.2	130.3	121.5	13.4	A*
Serine	79.1	78.6	78.9	4.5	
Asparagine	107.9	134.2	107.4	25.3	
Glutamic acid	82.4	60.7	80.2	7.0	A*, B*
Glutamine	226.3	183.7	188.7	14.4	A*
Proline	71.7	87.2	84.7	4.6	A*
Glycine	234.8	191.2	225.5	9.6	A*, B*
Alanine	220.7	244.0	236.3	17.2	
Citrulline	79.4	105.2	97.2	3.9	A*
Valine	244.3	462.9	366.6	13.4	A*, B*
Cystine	13.5	14.6	13.8	.6	
Methionine	13.5	17.8	15.6	2.0	A†
Isoleucine	112.7	196.1	165.5	10.8	A*, B*
Leucine	130.2	256.0	207.8	11.0	A*, B*
Tyrosine	45.5	67.4	60.3	6.6	A*
Phenylalanine	48.3	65.5	60.0	5.2	A*
Tryptophan	23.5	33.2	28.0	4.0	A*
Ornithine	51.1	73.5	65.2	2.5	A*
Lysine	69.4	98.9	98.7	6.0	A*
Histidine	47.5	59.7	53.4	1.7	A*, B†
3-Methyl histidine	.3	.2	.5	.7	
Arginine	82.1	107.7	102.0	6.9	A*
S-Containing AA ³	27.0	32.5	29.4	2.1	A†
BCAA ⁴	487	915	740	30.1	A*, B*
BCAA:Glycine	2.2	4.8	3.3	.2	A*, B*
EAA ⁵	872	1428	1219	55	A*, B*
NEAA ⁶	1030	987	1010	54	
EAA plus NEAA	1902	2415	2229	95	A*

¹C = Untreated; F = formic acid-treated; G = formaldehyde-treated. Values are least squares means (n = 11).

²Single degree of freedom orthogonal contrasts: A = untreated versus treated, B = formic versus formaldehyde.

³Sulfur-containing AA, sum of methionine plus cystine.

⁴Branched-chain AA, sum of valine, isoleucine plus leucine.

⁵Essential AA, sum of lysine, histidine, arginine, threonine, valine, methionine, isoleucine, leucine, tryptophan plus phenylalanine.

⁶Nonessential AA, sum of asparagine, serine, glutamic acid, glutamine, alanine, glycine plus proline.

†P < .10.

*P < .05.

Depressed milk protein has been associated with high forage, low energy diets (33). Animals fed treated silages in trial 2 had higher milk protein concentrations (Table 10), and a similar trend was seen in trial 1 (Table 4). Fish meal supplementation increased milk protein concentration. Increased post-ruminal supply of AA has increased milk protein concentration (10).

Milk urea concentration has been used as an indicator of relative protein to energy intake

and efficiency of ruminal N capture (2, 28). Milk urea in trial 1, part 1, was not different among silages (Table 4), and overall concentrations were lower than in part 2, in which C gave higher milk urea concentration than F or G (Table 8). The sequence by fish meal interaction in trial 1, part 2, indicated increased milk urea when fish meal was fed, regardless of whether fish meal was fed in the first or second period of the crossover. Diets based on C led to the highest milk urea concentrations,

which implied that the ratio of degradable protein to energy intake was greater than optimal.

Plasma urea concentrations in trial 1 followed a pattern similar to milk urea concentrations. Plasma urea in trial 2 was lower for C and G compared with F (Table 11). This reduction may have been due to the higher N intake on diet F. Plasma glucose levels were higher in trial 2 than trial 1, but they were not affected by silage source. This was not surprising, because animals in trial 2 received a higher energy diet, and the lower energy requirements for these midlactation cows were met more easily.

Increased plasma BCAA concentrations and plasma BCAA:Gly ratio have been associated with improved protein status (4). Plasma BCAA and BCAA:Gly ratio increased when treated silages were fed in all experiments (Tables 7 and 11). Kung et al. (19) reported increased plasma BCAA and EAA in dairy cattle fed higher dietary protein concentrations and greater amounts of UIP. The results from the present study probably are due to a combination of improved supplies of AA and energy, rather than protein alone, in animals receiving treated silages. Glutamine, a major carrier of NH_3 , was elevated on C diets, possibly in response to increased need for N excretion.

In vitro N digestibility showed that alfalfa treated with formic acid or formaldehyde was more resistant to rumen degradation, but overall N digestibility was not different from the control (Table 3), indicating that intestinal protein digestibility was not depressed. In vivo measurements of NAN flows also revealed greater rumen passage of treated silage protein (Table 6). In addition, rumen NH_3 concentrations tended to be highest for untreated silage (Table 5), indicating greater protein degradation. In vivo N escape likely was overestimated, probably because of inaccuracies in apportioning protein flow between microbial and escaped protein. Although absolute values may have been inaccurate, both F and G treatments appeared to give relative increases of silage protein escape when compared with C treatment. Total tract apparent N digestibility was similar for all silages (Table 8) and slightly lower than that found in vitro. Microbial protein yields were not different, probably because ruminal N was in excess, and energy intake was not substantially different among

diets. Similar concentrations and molar proportions of VFA (Table 5) suggest that rumen DM digestion was unaffected by silage treatment. Fish meal supplementation had no clear effect on total tract apparent N digestibility. It was not clear why fish meal appeared to decrease apparent DM digestibility.

CONCLUSIONS

Formic acid treatment of wilted alfalfa silage was effective in reducing N degradation in the silo and the rumen and in increasing milk production. Application of formic acid is difficult because of its corrosive nature and cost. Additional work must be done to develop accurate on-farm tests to predict when formic acid application is appropriate and what application rate is optimal. Response of early lactation cows fed high energy diets containing treated alfalfa silage as the sole forage needs to be quantified.

Treatment of wilted alfalfa silage with the formaldehyde-containing additive GrainmaxTM also improved protein recovery from the silo and milk production. However, GrainmaxTM was not as effective as formic acid in reducing silage NPN and maintaining milk protein secretion, possibly because of the low application rate or its inability to reduce herbage pH rapidly.

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