Effect of Feeding Macerated Alfalfa Silage on Nutrient Digestibility and Milk Yield in Lactating Dairy Cows[1]

G. A. BRODERICK,*,[2] R. G. KOEGEL,* M.J.C. MAURIES,†,[3]
E. SCHNEEBERGER,‡ and T. J. KRAUS§
*Agricultural Research Service, USDA,
US Dairy Forage Research Center,
1925 Linden Drive West, Madison, WI 53706
†Ecole Superieure D'Agriculture, 55 Rue Rabelais, 49007 Angers, France
‡Austrian Agricultural University, Vienna
§New Holland North America, New Holland, PA 17557

ABSTRACT

Five feeding studies were conducted with 141 lactating Holstein cows comparing macerated and control alfalfa silage harvested at two cuttings in each of 2 yr. Overall, silage made from macerated alfalfa contained more ash (suggesting improved soil contamination); greater fiber and lower nonprotein nitrogen (NPN) content suggested greater fermentation in the silo. In a digestion study, two diets were fed containing [dry matter (DM) basis] 72% of either control or macerated second-cutting alfalfa. Apparent digestibility of neutral detergent fiber and acid detergent fiber (ADF) was increased by maceration, and similar changes in digestibility were observed with Yb or indigestible ADF as marker; indigestible ADF was used as a marker in later studies. Lactation trials were conducted with first- and second-cutting alfalfa from each year. In each study, diets were formulated from alfalfa silage plus concentrate based on processed high moisture ear corn; mean compositions were (DM basis): negative control (61% control alfalfa silage), macerated (61% macerated alfalfa silage), and positive control (50% control alfalfa silage). All diets contained 2% crude protein from either roasted soybeans or low-solubles fish meal; soybean meal was added to make the positive control isonitrogenous (but not equal in ruminal undegraded protein). Milk yield was greater on macerated than negative control in two of four trials but not different in the other two trials. Yields of milk and milk components were not different between macerated and positive control in one of four trials. Versus the negative control, milk fat synthesis was depressed on macerated alfalfa in one trial. Overall performance on macerated versus negative control indicated greater apparent digestibility of organic matter (OM), greater yield of milk, protein, and solids not fat, but lower milk fat content. Yields of milk and milk components were greater overall on positive control versus macerated. Estimation of net energy for lactation (NE_L) from maintenance, milk yield, and body weight gain indicated that control and macerated alfalfa silage contained, respectively, 1.36 and 1.42 Mcal of NE_L of OM, an increase of about 5% due to maceration of alfalfa in these trials.

(**Key words:** maceration, alfalfa silage)

Abbreviation key: AS = alfalfa silage, **HMEC** = high-moisture ear corn, **MUN** = milk urea N.

INTRODUCTION

Ease of mechanization, lower field losses, and reduced weather damage have made ensiling the method of choice for harvesting alfalfa in the Midwest United States. Increasing the ruminal fermentability of alfalfa silage fed to dairy cows would be as beneficial as feeding more concentrate because it would increase the supply of energy from VFA and protein from microbial protein synthesis. Maceration, a method of mechanical conditioning originally developed to increase field-drying rate, was also found to increase forage digestibility. Studies with stationary processing equipment (32) showed that macerating alfalfa before drying as hay increased rate of microbial colonization of stems and rate and extent of NDF digestion in ruminal in vitro incubations (17) and total tract digestion of fiber in sheep and yield of FCM in goats (16). More recently, work conducted with a field-going machine (20) indicated that macerating alfalfa before ensiling reduced NPN formation in the silo and protein degradation in the rumen (25). Macerated alfalfa silage was found to contain about 10% more NE_L when fed to lactating cows (14); average improvement in milk yield with feeding of macerated alfalfa hay and silage in one study was

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[2]Corresponding author.
[3]Present address: Conseiller Scientifique Nutrition Animale du Syndicat National des Deshydrateurs de France, Angers, France.

2.6 kg/d (23). An updated version of the field-going macerator that yields the same degree of mechanical conditioning as previous models has been developed (19); this machine is capable of producing sufficient forage for large feeding studies with lactating cows.

The objective of this research was to use more statistically powerful studies to confirm results from previous work and to quantify the magnitude of improvement in nutritional value due to maceration of alfalfa. Four large-scale feeding trials and one smaller digestibility trial were conducted with alfalfa silage (**AS**) harvested in two cuttings during consecutive years.

MATERIALS AND METHODS

Alfalfa Harvest and Composition

In 1996, alfalfa was harvested June 13 to 15 (first cutting) and July 10 to 16 and July 23 (second cutting) with either a conventional mower conditioner (control) or a macerator (macerated; 19). In 1997, first-cutting alfalfa was harvested on June 9 and 10 (immature) and June 26 and 27 (mature), and second cutting on July 11 and 12 with the same machinery as in 1996. During each harvest, alfalfa was field wilted to approximately 40% DM; target DM content was reached the day of cutting for macerated and the day after cutting for control. Alfalfa was chopped to a theoretical length of 2.9 cm and ensiled in upright concrete stave tower silos; twice as much control as macerated AS was harvested both years at the first and second cuttings. About the same amount of control and macerated AS harvested on July 23, 1996, was ensiled in plastic bags (Ag-Bag International Ltd; Warrenton, OR). Weekly composite samples of AS were prepared from daily 0.5-kg samples collected throughout feedout in each trial and stored at –20°C until analyzed. At the end of each feeding trial, weekly composites were thawed, water extracts were prepared (24), and pH was measured. Extracts were deproteinized (24) then analyzed for total AA and NH_3 (5) and for NPN (24). Thawed composites then were dried at 60°C (48 h) and ground through a 1-mm screen (Wiley mill; Arthur H. Thomas, Philadelphia, PA). These samples were either analyzed directly (trial 1.1) or further composited by mixing equal amounts of sample DM to obtain samples that represented 3-wk (trials 1.2 and 1.3) or 4-wk (trials 2.1 and 2.2) periods. These samples then were analyzed for DM at 105°C, ash and OM (1), total N (Leco 2000; Leco Instruments, Inc., St. Joseph, NE), and for NDF and ADF (13) with heat-stable α-amylase (29) and Na_2SO_3 (15). Mean composition data for the control and macerated AS harvested over the 2 yr are in Table 1.

TABLE 1. Effect of maceration on mean composition of alfalfa silage.[1]

Component	Control	Macerated	SEM[2]	$P > F$[3]
DM, %	43.4	42.2	0.8	0.28
CP, % of DM	20.5	20.2	0.5	0.50
Ash, % of DM	10.4	11.6	0.5	<0.01
NDF, % of DM	43.2	44.8	0.9	0.04
ADF, % of DM	34.8	36.0	0.8	0.06
pH	4.99	4.87	0.04	0.04
NH_3-N, % of total N	14.5	12.8	0.9	0.65
Total AA-N, % of total N	34.7	29.7	1.1	<0.01
NPN, % of total N	44.4	40.4	1.1	0.01

[1]Alfalfa harvested at one maturity during first cutting and two maturities during second cutting in 1996, and harvested at two maturities during first cutting and one maturity during second cutting in 1997.

[2]SEM = Standard error of the mean.

[3]Probability of an effect of maceration.

Trial 1

Trial 1.1. Twenty multiparous, lactating Holstein cows [BW, 539 ± 51 kg; milk yield, 37 ± 4 kg/d; parity, 2.5 ± 1.5; and DIM, 33 ± 17 (mean ± SD)] were blocked by DIM into 10 groups of two. Within each group, cows were randomly assigned to one of two diets—fed as TMR—that contained (DM basis) 72% control or macerated AS harvested on July 23, 1996 (second cutting); rolled high-moisture ear corn (**HMEC**) was the principal component of the concentrate (Table 2). Cows were milked twice daily and individual milk yields were recorded; however, milk yield data were not analyzed statistically in this trial. Cows were housed in tie stalls, had free access to water throughout the trial, and were fed their respective TMR for a total of 21 d, offered once daily at 1100 h. Orts were collected and recorded daily, and feeding rate was adjusted daily to yield orts of 5 to 10% of intake. Weekly composites of AS, HMEC, TMR, and orts were prepared from daily samples of about 0.5 kg that were stored at –20°C. Weekly samples of ground shelled corn were stored at 21 to 24°C. Proportions of dietary DM from each ingredient on an as-fed basis were adjusted weekly based on DM determined by drying weekly composites at 60°C (48 h) for AS and HMEC and at 105°C (1) for ground shelled corn. After drying, ingredients and TMR were ground through a 1-mm screen (Wiley mill). Composites were analyzed as described earlier for ash, total N, NDF, and ADF, and OM was computed.

An aqueous solution of the external marker Yb was prepared (8) and sprayed on ground shelled corn as it was mixed in a vertical mixer. Ground shelled corn averaged 1.7% of the DM in both diets; Yb-labeled corn replaced unlabeled corn during the last 14 d of the trial. The Yb concentration in the TMR averaged 0.356 mg/kg of DM. Fecal grab samples were taken at five different times: 1000 h on d 17, 2400 h on d 18, 0500 h on d 19,

TABLE 2. Composition of diets fed (% of DM) in trials 1.1, 1.2, and 1.3 with alfalfa silage (AS) harvested in 1996.[1]

	Trial 1.1		Trial 1.2			Trail 1.3		
Ingredient	Control	Macerated	NC	M	PC	NC	M	PC
Control AS (first cutting)	. . .	. . .	61.3	. . .	51.4	. . .	. . .	. . .
Macerated AS (first cutting)	. . .	. . .	. . .	59.8	. . .	. . .	. . .	. . .
Control AS (second cutting)	72.4	. . .	. . .	. . .	. . .	63.7	. . .	48.6
Macerated AS (second cutting)	. . .	71.7	. . .	. . .	. . .	. . .	63.9	. . .
Rolled high moisture ear corn	24.8	25.5	35.0	36.5	41.2	31.3	31.2	40.8
Ground shelled corn-Yb[2]	1.7	1.7	. . .	. . .	. . .	. . .	. . .	. . .
Solvent soybean meal	. . .	. . .	. . .	. . .	3.4	. . .	. . .	5.4
Low solubles fish meal	. . .	. . .	2.9	2.9	2.9	. . .	. . .	. . .
Roasted soybeans	. . .	. . .	. . .	. . .	. . .	4.2	4.1	4.1
Sodium bicarbonate	. . .	. . .	. . .	. . .	0.4	. . .	. . .	0.4
Dicalcium phosphate	0.6	0.6	0.3	0.3	0.2	0.3	0.3	0.2
Trace mineral salt[3]	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Potassium and magnesium sulfate[4]	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Vitamin ADE concentrate[5]	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Composition								
CP	18.7	18.0	18.0	17.8	18.1	17.0	17.1	17.2
NDF	34	34	34	34	31	30	31	26

[1]NC = Negative control; M = macerated; PC = positive control.

[2]Provided (per kg of DM): 0.358 and 0.355 mg Yb, respectively, to Control and Macerated diets.

[3]Provided (per kg of DM): Mn, 27 mg; Zn, 27 mg; Fe, 17 mg; Cu, 7 mg; I, 0.40 mg; Se, 0.30 mg; and Co, 0.10 mg.

[4]Provided (per kg of DM): Mg, 110 mg; K, 180 mg; S, 220 mg.

[5]Provided (per kg of DM): vitamin A, 3880 IU; vitamin D, 730 IU; and vitamin E, 7.3 IU.

1900 h on d 20, and 1400 h on d 21. Fecal samples were dried in forced-draft ovens (60°C; 72 h) then ground through a 1-mm screen (Wiley mill) and analyzed as described for DM, OM, total N, NDF, and ADF. The TMR composites from both diets for the last 7 d of trial also were dried at 60°C (48 h) and ground through a 1-mm screen. Dried, ground TMR composites and fecal samples were analyzed for Yb by direct current plasma spectroscopy (SpectraMetrics, Inc., Andover, MA) by the methods of Combs (8) and for indigestible ADF (the ADF remaining after 144 h of in vitro ruminal incubations; 9). Indigestible ADF and Yb were used as internal and external markers, respectively, to estimate apparent digestibility of nutrients (7).

Trial 1.2. First-cutting AS harvested in 1996 was fed in this study. Forty-two multiparous, lactating Holstein cows [BW, 643 ± 59 kg; milk yield, 39 ± 5 kg/d; parity, 3.4 ± 1.6; and DIM, 140 ± 44 (mean ± SD)] were fed a standard covariate TMR containing (DM basis) 60% alfalfa silage, 22% corn silage, 13% HMEC, 3% roasted soybeans, 1% solvent soybean meal, plus minerals and vitamins, 17% CP and 34% NDF for at least 21 d before starting on the trial. Cows were blocked by DIM into 15 groups of three; within each group, cows were randomly assigned to one of three diets, fed as TMR, and fed their respective diets for 10 wk. Diets consisted (Table 2) of negative control with 61% control alfalfa, macerated with 60% macerated alfalfa, and positive control with 51% control alfalfa; diets also contained rolled HMEC, low-solubles fish meal (Sea Lac; Zapata-Haynie Co., Hammond, LA) and soybean meal. All cows were injected with bST (500 mg/d of Posilac, Monsanto, St. Louis, MO) beginning on d 1 of the trial, and then injected at 14-d intervals throughout. Cows were housed in tie stalls and had free access to water throughout the trial. The TMR were fed once daily at 1100 h; orts were collected and recorded once daily. The feeding rate was adjusted daily to yield orts of 5 to 10% of intake. Weekly composites of AS, HMEC, TMR, and orts were prepared from daily samples of about 0.5 kg that were stored at –20°C. Weekly samples also were taken of soybean meal and fish meal and stored at 21 to 24°C. The AS and HMEC contents of diets (as-fed basis) were adjusted weekly based on DM determined at 60°C for 48 h. Body weights were measured on three consecutive days at the start and end of the trial to compute BW change.

Cows were milked twice daily and individual milk yields were recorded at each milking. Milk yield data were obtained during the 14 d preceding the start of the trial (covariate period) and from the last 8 wk of the trial. Milk samples were collected at two consecutive milkings (p.m. and a.m.) at the end of wk 4, 6, 8, and 10 of the trial, and each sample was analyzed for fat, protein, SNF, and SCC by infrared analysis (AgSource, 403 Cedar Av. West, Menomonie, WI) (1). Milk was deproteinized and analyzed for milk urea N (**MUN**) by a colorimetric assay (11).

Concentrations and yields of fat, protein and SNF were computed as the weighted means from a.m. and p.m. milk yields on each test day. Yield of 3.5% FCM was computed as described by Sklan et al. (33). Efficiency of feed conversion was computed for each cow by dividing biweekly yield of 3.5% FCM by biweekly mean DMI over the last 8 wk of the trial. Two fecal grab samples also were collected from each cow at the end of wk 4 and 7 of the trial; samples were dried at 60°C for 72 h and ground through a 1-mm screen.

Dry matter contents were determined by drying weekly composites at 60°C (48 h) for AS and HMEC and at 105°C (1) for fish meal and soybean meal. Weekly samples of TMR also were dried at 60°C (48 h). After drying, ingredients and TMR were ground through a 1-mm screen. Three 3-wk composites covering the last 9 wk of the trial were made from dried, ground ingredients by mixing equal DM from weekly samples. Composites were analyzed as described for DM, OM, total N, NDF, ADF, and indigestible ADF.

Six multiparous, lactating Holsteins cows that were fitted with permanent ruminal cannulae were randomly assigned to two, 3 × 3 Latin square with 21-d periods and fed the same experimental diets. Mean (±SD) milk yield and DMI during the trial were, respectively, 29.3 (±5.1) and 24.4 (±2.3) kg/d and were not analyzed statistically. Samples of strained ruminal fluid, taken on d 21 of each period from the ventral sac of cannulated cows at 0 (just prior to feeding), 1, 2, 3, 4, and 6 h after feeding, were prepared by straining rumen contents through two layers of cheesecloth. After pH was measured, two subsamples were preserved by adding 0.2 ml of 50% (vol/vol) H_2SO_4 per 10 ml of ruminal fluid for later analysis of NH_3 and total free AA, and by adding 5 ml of formic acid per 5 ml of ruminal fluid for later analysis of VFA (6). These samples were stored at –20°C. Later, ruminal samples were thawed, centrifuged (15,000 × *g*, 4°C, 15 min), and analyzed for NH_3 and total free AA (5) and for VFA (6).

Trial 1.3. Second-cutting AS harvested on July 10 to 16, 1996, was fed in this study. Forty-two multiparous Holstein cows [BW, 604 ± 55 kg; milk yield, 44 ± 4 kg/d; parity, 3.1 ± 1.6; and DIM, 64 ± 22 (mean ± SD)] were used in the lactation phase of this trial. The protocol and analytical methods used were the same as trial 1.2 except that roasted soybeans (12), rather than low-solubles fish meal, were fed as a source of RUP. Also, two cows fed each diet were dropped from the trial because they either developed clinical mastitis or had very high SCC (>3.5 million) coupled with low production; thus, production data were collected from 12 cows on each experimental diet. A 3 × 3 Latin square study was used to assess changes in ruminal metabolites using the same six ruminally cannulated cows and protocol as in trial 1.2. Mean (±SD) milk yield and DMI during the trial were, respectively, 38.6 (±6.0) and 25.6 (±3.1) kg/d and also were not analyzed statistically. Ruminal fluid was sampled and analyzed as in trial 1.2, except samples were taken at 0, 1, 2, 3, 4, 6, 9, 12, 15, 18, 21, and 24 h after feeding.

Trial 2

Trial 2.1. First-cutting AS harvested on June 9 and 10 (immature) and June 26 and 27 (mature), 1997 was fed in this study. Thirty-six multiparous and six primiparous lactating Holstein cows [BW, 607 ± 83 kg; milk yield, 44 ± 6 kg/d; parity, 3.0 ± 1.7; and DIM, 111 ± 49 (mean ± SD)] were blocked by DIM into 12 multiparous and two primiparous groups of three. The 14 groups of cows were randomly allotted to three different dietary regimes such that two sets of five groups (four of multiparous and one of primiparous; 15 cows total) were fed diets containing either immature (trial 2.la) or mature AS (trial 2.lb), and the four other groups of multiparous cows were fed diets containing immature and mature AS (trial 2.1c). Within each group, cows were randomly assigned to dietary sequences in 3 × 3 Latin squares; groups within sets represented replicates of the Latin square. Periods were 4 wk (trial total, 12 wk). Diets fed in trials 2.la and 2.lb were similar to that used in trial 1.2 (Table 3): negative control with 57 or 61% control AS, macerated with 59 or 60% macerated AS, and positive control with 47 or 51% control AS; plus HMEC, low-solubles fish meal, and soybean meal to equalize CP. Diets fed in trial 2.lc were the negative controls from trials 2.la (57% control immature AS) and 2.lb (61% control mature AS) plus the macerated from trial 2.lb (60% mature macerated AS) (Table 3). The HMEC used in this study was ground through a 1-cm screen using a hammer mill (Meter/Mill; Clay Equipment Corp., Cedar Falls, IA). Diets contained 18.4 to 18.8% CP but differed substantially in NDF (Table 3). Milk samples were collected at two consecutive milkings (p.m. and a.m.) on d 19 and 26 of each period. A single fecal grab sample was collected from each cow on d 27 of each period. Protocols for care and feeding of the cows, methods for sampling and analyses of feed, milk, and feces were as described earlier.

Trial 2.2. Only immature second-cutting AS harvested in 1997 was fed in this study. Twenty-one multiparous lactating Holstein cows [BW, 615 ± 62 kg; milk yield, 45 ± 5 kg/d; parity, 3.4 ± 1.5; and DIM, 46 ± 16 (mean ± SD)] were blocked by DIM into seven groups of three and randomly allotted to dietary sequences in 3 × 3 Latin squares. Diets were similar to those used in trial 2.la (Table 3): negative control with 6l% control AS, macerated with 60% macerated AS, and positive

control with 51% control AS, plus HMEC, low-solubles fish meal and soybean meal. The HMEC fed in this study also was ground through a 1-cm screen by using a hammer mill. All other protocols for care and feeding of the cows, methods for sampling and analyses of feed, milk, and feces were as described for trial 2.1.

Statistical Analysis

All statistical analyses were performed by the general linear models procedure of SAS (30). Significance was declared at $P \leq 0.10$ in individual trials and at $P \leq 0.05$ in overall statistical analyses. Overall silage DM content and composition of water extracts made from weekly trial samples of control and macerated AS were analyzed with a model that included trial, treatment, and trial-by-treatment interaction. Except for NH_3 content ($P = 0.05$), the trial-by-treatment interaction was not significant ($P \geq 0.13$), and these residuals were pooled with experimental error. Overall CP, ash, NDF, and ADF contents of dried composites from control and macerated AS were analyzed with a model that included trial, treatment, and trial-by-treatment interaction, weighted for the number of weeks represented by each composite. No trial-by-treatment interactions were significant ($P \geq 0.32$) so these residuals were pooled with experimental error.

In trial 1.1, apparent nutrient digestibilities were analyzed with a model that included AS treatment, marker (Yb vs. indigestible ADF) and marker-by-treatment interaction. In trials 1.2 and 1.3, the first 2 wk were allowed for adaptation and one mean was computed for each cow over the last 8 wk of the trial for all intake and production variables. A single mean also was computed for each cow from apparent nutrient digestibilities observed in wk 4 and 7. Data were analyzed with a model that included diet and covariate milk yield. Ruminal pH and metabolite concentrations in each of trials 1.2 and 1.3 were analyzed as a 3×3 Latin square, replicated twice, with a model that included diet, square cow-within-square, period, and period-by-diet interaction. Except for molar proportion of ruminal isobutyrate in trial 1.2 ($P = 0.03$), no period-by-diet interaction was significant ($P \geq 0.15$). Orthogonal contrasts were used to compare: 1) macerated versus negative control and 2) macerated versus positive control.

In trials 2.1 and 2.2, mean intake and production data (averaged over the last 2 wk of each period), and apparent digestibilities were analyzed as a 3×3 Latin square, replicated five or four times (trial 2.1) or seven times (trial 2.2), with a model that included diet, square, cow-within-square, period, and period-by-diet interaction. Significant period-by-diet interactions were detected for DMI ($P = 0.08$) and protein yield ($P = 0.02$) in trial 2.lc; no other period-by-diet interactions were significant ($P \geq 0.12$). Orthogonal contrasts were used to compare macerated versus negative control and macerated versus positive control.

TABLE 3. Composition of diets fed (% of DM) in trials 2.1 (first cutting) and 2.2 (second cutting) with alfalfa silage (AS) harvested in 1997.[1]

	Trial 2.1						Trial 2.2		
	Immature			Mature			Immature		
Ingredient	INC	IM	IPC	MNC	MM	MPC	NC	M	PC
Control AS (first, immature)	57.0	. . .	47.1	. . .	. . .	. . .	. . .	. . .	. . .
Macerated AS (first, immature)	. . .	58.5	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Control AS (first, mature)	. . .	. . .	. . .	60.5	. . .	50.7	. . .	. . .	. . .
Macerated AS (first, mature)	. . .	. . .	. . .	. . .	59.6	. . .	. . .	. . .	. . .
Control AS (second, immature)	. . .	. . .	. . .	. . .	. . .	. . .	60.5	. . .	50.5
Macerated AS (second, immature)	. . .	. . .	. . .	. . .	. . .	. . .	. . .	60.4	. . .
Ground high moisture ear corn	39.2	37.8	45.4	31.2	31.8	38.1	35.8	35.9	42.1
Solvent soybean meal	. . .	. . .	3.4	4.8	5.0	7.3	. . .	. . .	3.4
Low solubles fish meal	3.2	3.1	3.1	2.9	3.0	2.9	2.9	2.9	2.9
Sodium bicarbonate	. . .	. . .	0.4	. . .	. . .	0.4	. . .	. . .	0.4
Dicalcium phosphate	0.2	0.2	0.2	0.2	0.2	0.2	0.4	0.4	0.3
Salt	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Vitamin-mineral concentrate[2]	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Composition									
CP	18.6	18.4	18.4	18.7	18.4	18.8	17.7	17.0	18.0
NDF	28	29	25	32	32	28	30	32	27

[1]INC = Immature negative control; IM = immature macerated; IPC = immature positive control; MNC = mature negative control; MM = mature macerated; MPC = mature positive control; NC = negative control; M = macerated; PC = positive control.

[2]Provided (per kg of DM): Zn, 56 mg; Mn, 46 mg; Fe, 22 mg; Cu, 12 mg; I, 0.9 mg; Co, 0.4 mg; Se, 0.3 mg; vitamin A, 6440 IU; vitamin D, 2000 IU; and vitamin E, 16 IU.

Overall production data from the trials containing the negative control, macerated, and positive control diets (trials 1.2, 1.3, 2.la and 2.lb, 2.2) were analyzed with a model that included trial, cow-within-trial, diet, and trial-by-diet interaction; data were weighted for the number of cows in each trial. No trial-by-diet interactions were significant ($P \geq 0.19$). When diet effects were significant ($P \leq 0.05$), mean separation was by least significant difference (35). Apparent digestibilities computed using indigestible ADF in these same five trials were analyzed for the negative control and macerated diets only with a model that included trial, diet, and trial-by-diet interaction; data also were weighted for the number of cows in each trial. No trial-by-diet interactions were significant ($P \geq 0.12$). Data on SCC were not analyzed statistically.

RESULTS AND DISCUSSION

Composition of Alfalfa Silage

Control and macerated AS fed in these studies were not different in DM and CP content, averaging 43% DM (60°C) and 20.4% CP over all feeding trials (Table 1). However, macerated AS contained more ash and NDF; the greater ADF content in macerated AS approached significance ($P = 0.06$). Elevated ash content in macerated AS may be due to more soil contamination occurring during alfalfa pickup with the maceration equipment used in these harvests. We should be able to modify our machinery to obtain macerated alfalfa forage with no greater soil contamination than conventionally harvested alfalfa. Results from previous studies indicated that macerated alfalfa did not contain more ash (16, 23). Elevated fiber content in alfalfa forage often reflects greater leaf loss during harvest (3); however, increased leaf loss normally would be accompanied by depressed CP. Elevated NDF and ADF may have resulted from greater fermentation in macerated AS relative to control AS due to greater breakdown of nonstructural carbohydrates. The pH as well as total AA and NPN contents of macerated AS all were lower than in control AS (Table 1). A more rapid pH drop associated and improved fermentation in the silo, partly caused by reduced O_2 in the ensiled forage from better compaction (18), has been observed with macerated AS. This finding may account for the lower NPN and total AA, the principal component of the NPN fraction in AS, that was observed in macerated AS in earlier studies (25) and in the present trials. Decreasing NPN content of hay-crop silages generally improves CP utilization in lactating cows (26). Similar NH_3 contents of control and macerated AS indicated both silages had normal, homolactic fermentations (21).

Nutrient Digestibility

A brief study (trial 1.1) was conducted to assess the reliability of indigestible ADF as an internal marker, relative to the external marker Yb (8), for quantifying total tract apparent digestibility in the diets to be used in these experiments. Although DM and OM were not affected, apparent digestibility was greater for NDF and ADF, and lower for CP, when the diet contained 72% macerated AS (Table 4). Maceration of alfalfa hay improved both in vitro (17) and in vivo (16) fiber digestion in sheep. The reduction in apparent CP digestibility likely was not due to a reduction in true digestibility but probably occurred because the macerated AS diet was lower in CP (Table 2). This would result in greater dilution of undigested dietary N by metabolic fecal N (34). Apparent digestibilities estimated with Yb all were greater than those estimated with indigestible ADF as internal marker; effect of marker was highly significant ($P < 0.01$) for all five nutrients (Table 4). The relative underestimation ranged from 8% (OM digestibility) to 23% (ADF digestibility). Assuming Yb was a more reliable marker, this result suggested that indigestible ADF concentrations may have been underestimated in the feces or overestimated in feed. However, marker-by-diet interaction was not significant ($P \geq 0.62$) for any of the five nutrients studied and the magnitude of difference due to diet was about the same regardless of marker for NDF, ADF, and CP, the three nutrients identified as having been altered in digestibility due to maceration (Table 4). Thus, the same effects on apparent digestibility would have been detected with either marker, and indigestible ADF appears to be reliable for quantifying the relative differences due to maceration of AS.

Overall apparent digestibilities determined by using indigestible ADF as internal marker in the feeding trials conducted with diets containing about 61% AS are in Table 5. Although numerically greater with macerated AS, there were no overall effects ($P \geq 0.17$) due to diet observed for digestibility of NDF, ADF, and CP. However, maceration of AS increased ($P < 0.01$) digestibility of OM, and there was a trend ($P < 0.08$) for increased digestibility of DM. Accounting for greater variation in soil silica contamination in macerated AS (Table 1) may explain this apparent difference between DM and OM digestibility. Maceration increased OM digestibility by 3.1% in these diets containing 61% AS and 39% concentrate. Hintz et al. (14) found that maceration increased DM digestibility by 16% in sheep fed diets consisting of 100% AS.

Animal Performance

Trial 1. Performance data from the two lactation studies conducted with AS from two harvests in 1996

TABLE 4. Effect of digestion marker and maceration of second cutting alfalfa silage on apparent digestibility of dietary nutrients in diets containing 72% forage (Trial 1.1).[1]

	Yb[2]		IADF[2]		Mean			Probabilities[4]		
Nutrient	C	M	C	M	C	M	SEM[3]	Diet	Marker	Marker × Diet
DM	65.6	65.3	59.5	59.7	62.5	62.5	0.4	0.99	<0.01	0.67
OM	67.2	66.3	61.4	60.9	64.3	63.6	0.4	0.21	<0.01	0.76
NDF	43.3	47.8	34.3	39.7	38.8	43.7	0.7	<0.01	<0.01	0.62
ADF	38.4	42.5	28.6	33.6	33.5	38.0	0.7	<0.01	<0.01	0.64
CP	66.0	62.9	59.2	56.5	62.6	59.7	0.6	<0.01	<0.01	0.81

[1]C = Control (72% DM from control alfalfa silage); M = macerated (72% DM from macerated alfalfa silage); IADF = indigestible ADF.

[2]Marker used in determining apparent digestibility.

[3]SEM = Standard error of the mean.

[4]Probability of an effect of diet (control versus macerated), marker (Yb versus IADF), or interaction of marker × diet.

are in Table 6. Although there was no effect on DMI and BW gain, orthogonal contrasts comparing negative control and macerated diets revealed that there was 2.4 kg/d greater milk yield, as well as increased yields of protein and SNF, with feeding of macerated first-cutting AS in trial 1.2. Moreover, yields of milk and milk components were not different ($P \geq 0.20$) between cows fed macerated and the higher concentrate positive control. Diet did not significantly affect yields of FCM and fat, milk content of fat, protein and SNF, and FCM/DMI. However, MUN was lower in cows fed macerated versus positive control. These results indicated a clear advantage for feeding lactating cows macerated, first-cutting AS and, in this trial, performance was similar on diets containing 59% macerated AS and 51% control AS (Table 2).

Production results were different in the lactation study conducted with AS harvested in 1996 at second cutting (trial 1.3; Table 6). Orthogonal contrasts comparing results obtained with feeding negative control and macerated diets revealed no differences for any performance trait ($P \geq 0.12$). Differences due to diet were almost all explained by greater production on the higher concentrate positive control diet: yields of milk, FCM, protein, and SNF all were greater ($P \leq 0.03$) in cows fed positive control versus macerated. Milk and protein yields on the positive control were, respectively, 4.2 and 0.22 kg/d and 5.2 and 0.24 kg/d greater than on macerated and negative control. Moreover, MUN was depressed ($P < 0.01$) on the positive control, suggesting that the improved protein yield on this diet may have resulted from its greater energy content, which, in turn, stimulated greater microbial protein formation in the rumen.

There were no effects of diet on ruminal pH or concentrations of NH_3, total AA, and total VFA in either trial 1.2 or 1.3 (Table 7). High ruminal NH_3 was not surprising in view of the dietary CP concentrations of 17 to 18% and indicated at least adequate supplies of RDP (31). Although not different among diets in trial 1.2, molar proportion of ruminal acetate was lower ($P = 0.02$), and there was a trend ($P = 0.07$) for lower acetate:propionate ratio on positive control versus macerated in trial 1.3. This probably was related to the relatively lower NDF content of the positive control diet (Table 2). However, the changes in ruminal acetate and acetate:propionate ratio, despite an NDF content of only 25% on this diet (Table 2), were surprisingly small (22) compared to what was found earlier (23). Previously, evidence had been obtained for a milk fat depression effect with feeding of macerated alfalfa forage (14). The lack of major shifts in ruminal VFA patterns in either of the present trials (Table 7) corroborates the lack of significant effects due to diet on milk fat content or secretion in either trial 1.2 or 1.3 (Table 6).

A number of differences between trials 1.2 and 1.3 (Table 2) may help explain the different responses in these two studies. Although mean milk protein yield was very similar in both trials, mean milk yield was 3.2 kg/d greater and DMI was 0.8 kg/d lower in trial 1.3. Greater milk yield would have increased absorbed

TABLE 5. Effect of macerating alfalfa silage on overall mean apparent digestibility of nutrients in diets containing about 61% forage.[1]

Nutrient	Control (60.6%)[2]	Macerated (60.5%)[2]	SEM[3]	$P > F$[4]
DM	60.0	61.1	0.4	0.08
OM	61.9	63.8	0.4	<0.01
NDF	44.2	45.0	0.6	0.17
ADF	37.9	38.8	0.5	0.32
CP	53.0	54.4	0.7	0.31

[1]Apparent digestibility was estimated using indigestible ADF as an internal marker.

[2]Mean proportion DM from either control or macerated alfalfa silage during the four trials.

[3]SEM = Standard error of the mean.

[4]Probability of a significant effect of maceration.

protein AA diverted to gluconeogenesis for lactose synthesis (10). Although the amount of first-cutting AS in negative control and macerated diets was lower (about 60% of DM) in trial 1.2, dietary NDF content actually was 4% units greater than on the corresponding diets containing second-cutting AS fed in trial 1.3. The CP content of diets fed in trial 1.2 was nearly 1% unit greater; supplemental low-solubles fish meal fed in trial 1.2 likely was a better source of RUP than the roasted soybeans fed in trial 1.3 (2). Thus, absorbable protein supply, relative to energy supply, probably was greater on trial 1.2 versus trial 1.3. Increased digestibility and NE_L from macerated AS (14) would be more easily detected on a diet in which lactation performance was limited by energy supply and absorbable protein was adequate.

Trial 2. Performance data from the three smaller lactation studies making up trial 2.1 conducted with AS harvested at two maturities during first cutting in 1997 are in Table 8. Trials 2.1a and 2.1b both involved three diets arranged as described earlier: negative control and macerated containing about 60% AS, and a positive control containing about 50% control AS. Not surprisingly, yields of milk and protein and milk content of protein and SNF were greatest on positive control when immature AS was fed (trial 2.1a). However, results obtained on the negative control and macerated diets were unlike the responses in trials 1.2 and 1.3. Although DMI, BW gain, and milk yield were not different, milk fat content, as well as yield of FCM and fat, all were greater on negative control than macerated. This was clear evidence that depressed milk fat synthesis occurred despite similar NDF contents of 28 and 29% in these two diets (Table 3). Milk fat content was lowest on positive control, which gave rise to similar fat yield as macerated. When mature AS was fed (trial 2.1b), DMI was greater and yields of protein and SNF were increased with macerated versus negative control. Yields of protein and SNF were greater on positive control than macerated.

Trial 2.1c was intended to determine whether maceration during harvest of more mature forage would yield

TABLE 6. Performance of lactating cows in Trials 1.2 and 1.3 when fed diets containing alfalfa silage (AS) harvested during 1996.

	Diet[1]					Contrasts[4]	
Variable	NC	M	PC	SEM[2]	$P > F$[3]	M vs. NC	M vs. PC
Trial 1.2 (first cutting AS)							
Covariate milk, kg/d	38.1	37.8	38.1	. . .	. . .	. . .	. . .
DMI, kg/d	26.8	27.4	26.8	0.7	0.73	0.49	0.51
BW gain, kg/d	0.33	0.45	0.34	0.15	0.81	0.57	0.58
Milk yield, kg/d	34.2	36.6	37.4	0.9	0.04	0.04	0.66
3.5% FCM, kg/d	36.0	37.5	38.6	1.4	0.39	0.39	0.61
Fat, %	3.84	3.67	3.77	0.14	0.65	0.36	0.58
Fat, kg/d	1.30	1.34	1.39	0.07	0.62	0.67	0.58
Protein, %	3.38	3.38	3.50	0.07	0.35	0.98	0.20
Protein, kg/d	1.15	1.23	1.30	0.03	0.01	0.08	0.20
SNF, %	8.72	8.76	8.90	0.11	0.47	0.83	0.35
SNF, kg/d	2.98	3.20	3.31	0.10	0.05	0.08	0.53
MUN, mg/dl	16.2	15.5	16.6	0.4	0.10	0.18	0.03
Efficiency[5]	1.36	1.37	1.44	0.05	0.46	0.88	0.32
Trial 1.3 (second cutting AS)							
Covariate milk, kg/d	42.2	43.6	43.2	. . .	. . .	. . .	. . .
DMI, kg/d	25.3	26.2	27.1	0.5	0.08	0.29	0.22
BW gain, kg/d	0.31	0.47	0.33	0.07	0.24	0.12	0.18
Milk yield, kg/d	37.9	38.9	43.1	0.7	<0.01	0.93	<0.01
3.5% FCM, kg/d	35.8	35.7	38.3	0.8	0.06	0.65	0.03
Fat, %	3.24	3.17	2.92	0.14	0.30	0.97	0.19
Fat, kg/d	1.20	1.19	1.23	0.05	0.80	0.79	0.51
Protein, %	3.07	3.10	3.27	0.06	0.02	0.41	0.06
Protein, kg/d	1.15	1.17	1.39	0.03	<0.01	0.93	<0.01
SNF, %	8.70	8.78	8.98	0.09	0.04	0.25	0.15
SNF, kg/d	3.28	3.33	3.81	0.08	<0.01	0.98	<0.01
MUN, mg/dl	13.9	13.9	12.2	0.3	<0.01	0.97	<0.01
Efficiency[5]	1.42	1.37	1.42	0.04	0.44	0.24	0.31

[1]NC = Negative control; M = macerated; MUN = milk urea N; PC = positive control.

[2]SEM = Standard error of the mean.

[3]Probability of an effect of diet.

[4]Probability of a significant difference of orthogonal contrasts.

[5]FCM/DMI.

TABLE 7. Effect on ruminal metabolites in Trials 1.2 and 1.3 of feeding diets containing control or macerated alfalfa silage (AS) harvested during 1996.

	Diet[1]					Contrasts[4]	
Variable	NC	M	PC	SEM[2]	$P > F^3$	M vs. NC	M vs. PC
Trial 1.2 (first cutting AS)							
pH	6.04	5.96	6.10	0.02	0.34	0.18	0.69
Ammonia, mM	20.5	19.5	17.5	0.8	0.98	0.88	0.97
Total AA, mM	6.23	7.17	6.70	0.78	0.44	0.26	0.83
Total VFA, mM	143.5	144.6	141.0	1.5	0.20	0.81	0.15
Mol/100 mol of total VFA							
Acetate (A)	61.9	61.2	61.4	0.3	0.20	0.14	0.93
Propionate (P)	21.7	23.1	22.1	0.4	0.23	0.11	0.48
A:P	2.88	2.68	2.82	0.06	0.21	0.10	0.48
Butyrate	11.3	11.1	11.7	0.1	0.11	0.64	0.05
Isobutyrate	1.25	1.13	1.18	0.02	0.07	0.03	0.32
Valerate	1.93	1.68	1.79	0.03	0.04	0.02	0.07
Isovalerate	1.89	1.77	1.89	0.04	0.61	0.57	0.36
Trial 1.3 (second cutting AS)							
pH	6.10	6.19	6.07	0.07	0.46	0.35	0.27
Ammonia, mM	11.7	11.5	10.9	0.5	0.54	0.86	0.40
Total AA, mM	2.34	2.46	2.70	0.31	0.72	0.80	0.61
Total VFA, mM	129.4	123.0	129.0	3.7	0.46	0.28	0.31
Mol/100 mol of total VFA							
Acetate (A)	63.5	64.3	61.5	0.5	0.05	0.35	0.02
Propionate (P)	20.4	19.6	21.1	0.6	0.28	0.43	0.13
A:P	3.17	3.30	2.95	0.10	0.16	0.44	0.07
Butyrate	11.5	11.6	12.5	0.3	0.13	0.89	0.09
Isobutyrate	1.03	1.05	1.06	0.02	0.36	0.48	0.44
Valerate	1.73	1.51	1.81	0.06	0.06	0.07	0.03
Isovalerate	1.82	1.84	1.96	0.06	0.34	0.77	0.27

[1]NC = Negative control; M = macerated; PC = positive control.

[2]SEM = Standard error of the mean.

[3]Probability of an effect of diet.

[4]Probability of a significant difference of orthogonal contrasts.

AS with feeding characteristics similar to less mature, conventionally harvested AS. Maceration did not produce AS giving lactation performance similar to AS that was 17 d less mature (Table 8); yields of milk, FCM, fat, protein and SNF, as well as FCM/DMI, all were greater on the negative control containing immature AS versus the macerated containing mature AS. However, BW gain was greater and DMI tended to be greater on mature macerated versus immature negative control. Performance on macerated mature AS generally was better than that on mature control AS; yield of milk, protein, and SNF all were greater on mature macerated versus mature negative control. Greater DMI on mature macerated contributed to lower FCM/DMI versus the mature negative control. Contradictory effects on MUN due to diet were observed with the orthogonal contrasts in the studies making up trial 2.1; MUN was lower on macerated than the negative control when cows were fed immature AS; however, the opposite occurred on mature AS.

Some of these apparently anomalous results may be related to interactions among amount of milk production, amount, and effectiveness of dietary fiber, and processing of HMEC. In trial 2.la, although NDF content was 28% in negative control diets and 29% on macerated diets (Table 3), milk fat synthesis was depressed on the macerated diet. These diets were 5 and 2% units lower in NDF than the corresponding diets fed in trials 1.2 and 1.3 (Table 2). Optimum dietary NDF varies with level of milk production and source of dietary forage (22). Varga (37) reported that a minimum of 25% "effective" NDF was required to maintain milk fat synthesis. Maceration appeared to reduce fiber effectiveness in the current studies. Depressed milk fat synthesis with feeding of macerated alfalfa hay and silage was observed previously in a trial in which NDF was 27 to 28% of dietary DM (14). Ruminal acetate was reduced, propionate was increased, and acetate:propionate ratio was depressed, but there was no difference in chewing time/unit of NDF intake in cows fed either control or macerated alfalfa (14). In another study, milk fat content was reduced in cows fed macerated alfalfa diets containing 30% NDF (23). However, this probably reflected dilution rather than depression of total synthesis of milk fat: milk yield was 2.6 kg/d greater, and fat yield was numerically greater, on macerated than

on control alfalfa. In addition to no differences in milk fat yield in trials 1.2 and 1.3 (Table 6), FCM yield in earlier work actually was greater in goats fed macerated alfalfa hay (16).

Intake of DM for macerated was greater than negative control with similar maturity in two of the three studies within trial 2.1; however, these greater DMI did not give rise to improved lactation performance (Table 8): 1.8 kg/d greater DMI on macerated than negative control was reflected in only small increases in yield of protein and SNF in trial 2.lb, while 2.3 kg/d greater DMI gave rise to only 1.2 kg/d more milk in trial 2.1c. Mean milk yield in trials 2.lb and 2.lc was, respectively, 4 and 3 kg/d less than that in trial 2.1a. Also, ground HMEC was fed in all three studies in trial 2.1 rather than the rolled HMEC fed in trials 1.2 and 1.3 (Table 2). Mean particle size of HMEC harvested in 1998 that was rolled and ground with the same equipment was, respectively, 2.0 and 1.0 mm (Alex Blohowiak, personal communication, 1999). Reducing particle size of HMEC

TABLE 8. Performance of lactating cows in Trial 2.1 when fed diets containing alfalfa silage harvested at first cutting in 1997.[1]

	Immature			Mature						
Variable	INC	IM	IPC	MNC	MM	MPC	SEM[2]	$P > F^3$	Contrasts[4]	
									IM vs. INC	IM vs. IPC
Trial 2.1a										
DMI, kg/d	25.4	24.7	24.6	. . .	. . .	. . .	0.5	0.42	0.27	0.95
BW gain, kg/d	0.37	0.58	0.38	. . .	. . .	. . .	0.19	0.67	0.43	0.45
Milk yield, kg/d	38.4	37.7	40.3	. . .	. . .	. . .	0.7	0.05	0.52	0.02
3.5% FCM, kg/d	39.4	36.3	36.5	. . .	. . .	. . .	1.0	0.08	0.05	0.85
Fat, %	3.58	3.29	3.07	. . .	. . .	. . .	0.1	<0.01	0.04	0.12
Fat, kg/d	1.39	1.23	1.19	. . .	. . .	. . .	0.05	0.02	0.03	0.52
Protein, %	3.11	3.12	3.23	. . .	. . .	. . .	0.02	<0.01	0.69	0.01
Protein, kg/d	1.21	1.17	1.28	. . .	. . .	. . .	0.03	0.07	0.37	0.02
SNF, %	8.56	8.62	8.73	. . .	. . .	. . .	0.03	<0.01	0.13	0.01
SNF, kg/d	3.33	3.23	3.46	. . .	. . .	. . .	0.09	0.21	0.44	0.08
MUN, mg/dl	18.0	16.9	16.2	. . .	. . .	. . .	0.4	0.01	0.07	0.18
Efficiency[5]	1.55	1.47	1.51	. . .	. . .	. . .	0.04	0.30	0.13	0.47
									MM vs. MNC	MM vs. MPC
Trial 2.1b										
DMI, kg/d	. . .	. . .	. . .	23.2	25.0	24.0	0.5	0.06	0.02	0.20
BW gain, kg/d	. . .	. . .	. . .	0.54	0.50	0.23	0.13	0.19	0.81	0.14
Milk yield, kg/d	. . .	. . .	. . .	34.3	35.5	36.1	0.8	0.28	0.54	0.35
3.5% FCM, kg/d	. . .	. . .	. . .	34.3	35.4	34.8	0.8	0.83	0.56	0.85
Fat, %	. . .	. . .	. . .	3.40	3.42	3.24	0.1	0.23	0.57	0.10
Fat, kg/d	. . .	. . .	. . .	1.18	1.23	1.16	0.04	0.61	0.50	0.33
Protein, %	. . .	. . .	. . .	3.17	3.16	3.27	0.04	0.16	0.95	0.10
Protein, kg/d	. . .	. . .	. . .	1.10	1.13	1.19	0.02	0.03	0.08	0.03
SNF, %	. . .	. . .	. . .	8.65	8.74	8.84	0.05	0.06	0.31	0.18
SNF, kg/d	. . .	. . .	. . .	3.02	3.13	3.24	0.05	0.02	0.06	0.04
MUN, mg/dl	. . .	. . .	. . .	17.3	18.3	17.2	0.4	0.10	0.07	0.05
Efficiency[5]	. . .	. . .	. . .	1.49	1.42	1.46	0.03	0.22	0.09	0.27
Trial 2.1c										
DMI, kg/d	24.7	. . .	. . .	23.4	25.7	. . .	0.4	<0.01	0.11	<0.01
BW change, kg/d	–0.03	. . .	. . .	0.55	0.46	. . .	0.17	0.06	0.06	0.71
Milk yield, kg/d	37.0	. . .	. . .	34.0	35.2	. . .	0.6	0.01	0.04	0.07
3.5% FCM, kg/d	37.5	. . .	. . .	34.6	35.4	. . .	0.6	0.01	0.02	0.38
Fat, %	3.73	. . .	. . .	3.69	3.45	. . .	0.11	0.16	0.08	0.13
Fat, kg/d	1.33	. . .	. . .	1.23	1.23	. . .	0.03	0.08	0.05	0.95
Protein, %	3.26	. . .	. . .	3.16	3.18	. . .	0.03	0.13	0.12	0.70
Protein, kg/d	1.18	. . .	. . .	1.06	1.13	. . .	0.01	<0.01	0.02	0.01
SNF, %	8.66	. . .	. . .	8.51	8.57	. . .	0.06	0.27	0.35	0.49
SNF, kg/d	3.17	. . .	. . .	2.88	3.05	. . .	0.05	<0.01	0.10	0.02
MUN, mg/dl	17.1	. . .	. . .	18.6	18.1	. . .	0.5	0.10	0.15	0.47
Efficiency[5]	1.52	. . .	. . .	1.48	1.37	. . .	0.04	0.03	0.01	0.05

[1]INC = Immature negative control; IM = immature macerated; IPC = immature positive control; MNC = mature negative control; MM = mature macerated; MPC = mature positive control; MUN = milk urea N.

[2]SEM = Standard error of the mean.

[3]Probability of a significant effect of diet.

[4]Probability of a significant difference of orthogonal contrasts.

[5]FCM/DMI.

TABLE 9. Performance of lactating cows in Trial 2.2 when fed diets containing alfalfa silage harvested at second cutting during 1997.[1]

	Diet					Contrasts[4]	
Variable	NC	M	PC	SEM[2]	$P < F$[3]	M vs. NC	M vs. PC
DMI, kg/d	26.1	26.4	26.5	0.7	0.91	0.74	0.94
BW gain, kg/d	0.55	0.58	0.46	0.11	0.75	0.89	0.48
Milk yield, kg/d	44.1	45.3	47.4	0.5	<0.01	0.09	<0.01
3.5% FCM, kg/d	42.9	43.7	43.1	0.8	0.72	0.45	0.54
Fat, %	3.38	3.30	2.99	0.08	<0.01	0.50	0.01
Fat, kg/d	1.47	1.49	1.40	0.04	0.23	0.77	0.11
Protein, %	3.05	2.99	3.03	0.03	0.38	0.17	0.38
Protein, kg/d	1.34	1.35	1.42	0.02	<0.01	0.66	0.01
SNF, %	8.50	8.43	8.46	0.07	0.79	0.50	0.76
SNF, kg/d	3.73	3.81	3.98	0.05	<0.01	0.27	0.02
MUN, mg/dl	17.3	16.1	16.9	0.2	<0.01	<0.01	<0.01
Efficiency[5]	1.67	1.69	1.65	0.06	0.86	0.80	0.59

[1]NC = Negative control; M = macerated; MUN = milk urea N; PC = positive control.

[2]SEM = Standard error of the mean.

[3]Probability of a significant effect of diet.

[4]Probability of a significant difference of orthogonal contrasts.

[5]FCM/DMI.

increased its ruminal fermentability (11) and may confound problems related to insufficient amount or ruminal effectiveness of dietary fiber.

Production results in the lactation study conducted with AS harvested in 1997 at second cutting (trial 2.2) are in Table 9. It was intended that the effect of maturity be replicated in this study; however, extensive rain damage resulted in complete loss of late maturity control AS. Although there were no effects of diet on DMI and BW gain, milk yield was greater on macerated than on negative control. The additional 10% of ground HMEC and soybean meal in the positive control increased yields of milk, protein, and SNF. The other significant effect detected in this trial was a depression in MUN on macerated versus both the negative and positive controls. Concentrations of MUN are influenced strongly by dietary CP (4); CP content of the macerated diet in this trial was 0.7 and 1.0% units lower than that of the negative and positive controls (Table 3). This likely explains the reduced MUN.

Overall Performance

Results from the overall analysis of animal performance data are summarized in Table 10. Not surprisingly, milk fat content was lowest on the positive control, which contained an average 11% units more concentrate than the other two diets. Although milk fat content was greater than on the positive control, overall milk fat content was lower on macerated than on negative control; however, milk fat yield was not different between macerated and negative control. Depressed milk fat often has been coupled with increased BW gain. Overall, BW gain was numerically 0.12 kg/d greater on macerated than on negative control; this effect was not significant (P = 0.38). Yield of milk, fat, protein, and SNF were greatest on the positive control, intermediate on macerated, and lowest on the negative control. Previous research with alfalfa hay (16) suggested that maceration by methods similar to those employed in these trials increased digestible energy by 10 to 15% over control. Computations reported by Hintz et al. (14) indicated that maceration increased NE_L content of AS by 10%, and most of that difference from control AS was due to greater BW gain. An assumed 10% greater NE_L in macerated than control AS would have yielded similar NE_L in the macerated diet (with 60% AS) as in positive control diet (with 50% AS). Although there were no significant differences between macerated and positive control in trial 1.2 (conducted with first cutting AS from 1996), yield of milk and milk components were lower on macerated than positive control in all other studies and in the overall analysis. Thus, production of cows fed macerated AS was not equivalent to 10% greater NE_L than control AS in the current trials.

Energy inputs and outputs were computed from the overall means of these trials to obtain estimates of NE_L contents of the control and macerated AS (Table 11). The NE_L requirements for maintenance, BW gain, and milk output (based on mean fat and SNF contents) were computed with NRC (27, 28) equations. The NE_L requirements for mean performance were 1.4 and 2.0 Mcal/d greater on, respectively, macerated and positive control. Subtracting the NE_L contribution computed for ration concentrate (1.86 Mcal/kg of DM; 28) yielded an estimate of the NE_L that must have been supplied from

TABLE 10. Overall mean performance of lactating cows fed control or macerated alfalfa silage harvested at two cuttings in each of 2 yr.[1]

Item	Diet[2]			SEM[3]	$P > F$[4]
	Negative control	Macerated	Positive control		
DM intake, kg/d	25.7	26.2	26.2	0.5	0.79
BW change, kg/d	0.37	0.49	0.34	0.11	0.38
Milk, kg/d	37.0[c]	38.4[b]	40.7[a]	0.6	<0.01
3.5% FCM, kg/d	36.7	37.4	38.6	0.6	0.55
Fat, %	3.50[a]	3.41[b]	3.30[c]	0.07	<0.01
Fat, kg/d	1.28[b]	1.29[ab]	1.30[a]	0.03	0.03
Protein, %	3.19	3.20	3.32	0.03	0.12
Protein, kg/d	1.17[c]	1.21[b]	1.33[a]	0.02	<0.01
SNF, %	8.66	8.70	8.84	0.05	0.21
SNF, kg/d	3.21[c]	3.32[b]	3.56[a]	0.06	<0.01
MUN,[5] mg/dl	15.9	15.5	15.3	0.3	0.16
Efficiency[6]	1.43	1.43	1.47	0.06	0.56

[a,b,c]Means in rows with different superscripts differ ($P < 0.05$).

[1]Mean performance data from five lactation trials weighted for the number of cows in each trial.

[2]Diets contained on average: negative control (60.6% control alfalfa silage), macerated (60.5% macerated alfalfa silage), and positive control (49.7% control alfalfa silage).

[3]SEM = Standard error of the mean.

[4]Probability of an effect of diet.

[5]Milk urea N.

[6]FCM/DMI.

AS. Per unit DM, control AS was computed to contain 1.22 or 1.18 Mcal/kg, versus 1.26 Mcal/kg for macerated AS (Table 11). Macerated AS contained greater ash than control AS, probably due to greater soil contamination as discussed earlier. Per unit OM, control AS was computed to contain 1.36 or 1.31 of Mcal/kg, versus 1.42 of Mcal/kg for macerated AS (Table 11). Comparing only the negative control and macerated diets, macerated AS was estimated to contain 4.5% more NE_L than control AS; averaging the estimates based on both the neg-

TABLE 11. Effect of maceration on NE_L content of alfalfa silage (AS) estimated from overall mean intake and performance data (Table 10).[1]

Component	Diet[2]		
	Negative control	Macerated	Positive control
Maintenance (638 kg),[3] Mcal/d	10.2	10.2	10.2
BW gain,[3] Mcal/d	1.9	2.5	1.8
Milk yield,[4] Mcal/d	25.8	26.6	28.0
NE_L requirement, Mcal/d	37.9	39.3	39.9
Total DM intake, kg/d	25.7	26.2	26.2
Concentrate DM intake, kg/d	10.2	10.4	13.2
Concentrate NE_L[5] Mcal/d	18.9	19.3	24.5
NE_L from AS, Mcal/d	19.0	20.0	15.3
AS DM intake, kg/d	15.5	15.8	13.0
AS NE_L, Mcal/kg DM	1.22	1.26	1.18
AS OM intake, kg/d	14.0	14.1	11.7
AS NE_L, Mcal/kg OM	1.36	1.42	1.31
Macerated/Control,[6] %	104.5		108.2

[1]Mean performance data from five lactation trials weighted for the number of cows in each trial.

[2]Diets contained on average: negative control (60.6% control alfalfa silage), macerated (60.5% macerated alfalfa silage), and positive control (49.7% control alfalfa silage).

[3]NE_L requirements (Mcal/d) for maintenance = $0.08 \times BW^{0.75}$ and for gain = $5.12 \times$ BW gain (28).

[4]NE_L requirement (Mcal/kg) for milk output = $0.09464 \times$ % fat + $0.049 \times$ % SNF − 0.0564 (27).

[5]Mean NE_L content of the concentrate portion of the three diets was computed to be 1.86 Mcal/kg of DM from NRC (28) tables.

[6]NE_L content of macerated AS, relative to control AS, computed by dividing estimated NE_L content of macerated AS (per unit of OM) by values for control AS estimated from feeding either the negative or positive control diet.

ative and positive controls yielded a value of 6.4% greater NE_L in macerated AS.

However, data from positive controls were excluded because possible negative associative effects on ruminal forage digestion that may occur at higher dietary concentrate (S. C. Valadones Filho, G. A. Broderick, R.F.D. Valadares and M. K. Clayton, 1999, unpublished) would have inflated the estimate of relative energy content. Thus, a value equal to 105% of control AS represented a conservative estimate of the relative NE_L content of macerated AS.

SUMMARY

Macerated AS harvested at two cuttings during each of two crop years contained more ash, suggesting greater soil contamination, as well as more fiber and less NPN, suggesting improved fermentation in the silo. Lactation studies conducted with cows fed diets containing 61% of DM from macerated and control AS showed that milk yield was greater on macerated than control AS in two of four trials but not different in the other two trials. Milk fat synthesis was depressed on macerated AS in one trial. Overall performance on macerated versus control AS indicated greater apparent digestibility of OM, greater yields of milk, protein, and SNF, lower milk fat content but similar milk fat yield. Yields of milk and milk components of cows fed 61% macerated AS was not equal to that of cows fed 50% were control AS. Maceration was estimated to increase NE_L content of AS by 5%.

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