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Effects of Corn Particle Size and Source on Performance of Lactating Cows Fed Direct-Cut Grass-Legume Forage

R. B. Reis,‡[1] F. San Emeterio,‡ D. K. Combs,‡ L. D. Satter,†‡[3] and H. N. Costa
‡Department of Dairy Science
University of Wisconsin, Madison 53706
†US Dairy Forage Research Center
USDA-Agricultural Research Service
Madison, WI 53706

ABSTRACT

We conducted two experiments to evaluate the effects of corn supplementation, source of corn, and corn particle size on performance and nutrient utilization of lactating dairy cows. In experiment 1, treatments were 1) direct-cut grass-legume forage without supplement, 2) direct-cut forage plus 10 kg DM of ground dry shelled corn-based concentrate, and 3) direct-cut forage plus 10 kg DM of coarsely ground high moisture ear corn-based concentrate. In experiment 2, treatments were 1) direct-cut grass-legume forage plus 10 kg DM of ground dry shelled corn-based concentrate, 2) direct-cut forage plus 10 kg DM of coarsely ground high moisture ear corn-based concentrate, and 3) direct-cut forage plus 10 kg of DM finely ground high moisture ear corn-based concentrate. Both experiments were designed as 3 × 3 Latin squares replicated three times. In experiment 1, yields of milk and milk protein increased with concentrate supplementation, but were not affected by source of corn. Solids-corrected milk yield tended to increase with grain supplementation. Dry matter intake increased with concentrate supplementation, but was not affected by source of corn or corn particle size. Corn supplements decreased ruminal pH and acetate to propionate ratio and increased ruminal propionate concentration. Grain supplements reduced ruminal ammonia concentration, increased concentration of urine allantoin, and increased the urinary allantoin to creatinine ratio. In the second study, fine grinding of high moisture corn reduced fecal starch plus free glucose levels and tended to increase its apparent digestibility. In both experiments, starch plus free glucose intake was higher on the diets with dry corn, but its utilization was not affected by source of corn.
(**Key words:** dairy, starch, grain processing, ruminant)

Abbreviation key: DCF = direct-cut forage fed with dry shelled corn-finely ground, **EM** = energy output in milk corrected for BW loss, **FF** = direct-cut grass-legume forage, **FF0** = direct-cut forage fed without grain supplement, **HMC** = direct-cut forage fed with high moisture ear corn-coarsely ground, **HMF** = direct-cut forage fed high moisture ear corn-finely ground, **SFG** = starch plus free glucose.

INTRODUCTION

The CP in fresh forages is rapidly and extensively degraded in the rumen, and can result in high concentrations of ruminal ammonia and excessive urinary N excretion in grazing dairy cattle (Kolver et al., 1998). As a consequence, the AA supply to the small intestine in pasture-fed dairy cows may limit milk production. Carruthers et al. (1997) and Reis and Combs (2000) reported that increasing the proportion of NSC and decreasing the proportion of structural carbohydrates of a pasture-based diet improved the utilization of dietary N and increased microbial protein synthesis in lactating cows. Starch degradability of corn is affected by moisture content and may affect the performance of grazing dairy cows (Rearte et al., 1997). Wilkerson et al. (1997) reported that nonfiber carbohydrate, CP, and OM digestibility were increased when high-moisture corn replaced dry corn in lactating cow diets. Particle size reduction improved starch utilization in dairy cattle fed diets supplemented with dry shelled corn (Moe and Tyrell, 1977) and high moisture ear corn (Ekinci and Broderick, 1997).

The objectives of these experiments were to compare starch utilization, nitrogen utilization, and lactation performance by cows fed direct-cut grass-legume for-

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Corresponding author: D. K. Combs; e-mail: dkcombs@facstaff.wisc.edu.
[1]Current address: Escola de Veterinária UFMG, Caixa Postal: 567 CEP: 30.123-970, Belo Horizonte, MG - Brasil.
[3]Current address: 1925 West Linden Drive, Madison 53706.

age supplemented with three types of corn supplement.

MATERIALS AND METHODS

Forage

Two experiments were conducted between June 5 and October 6 of 1996. Direct-cut forage utilized in both studies was harvested at 1600 h daily with a flail chopper from fields at the University of Wisconsin-West Madison Research Station. The forage was harvested at the late-vegetative stage of maturity and was predominantly alfalfa (*Medicago sativa* L.) with approximately 20 to 25% of quackgrass (*Elytrigia repens* L.).

Animals and Experimental Procedure

Nine rumen-cannulated cows housed in a stanchion barn at the Dairy Cattle Center, University of Wisconsin-Madison, were used in both experiments. Cows were assigned to three different treatments in experiments 1 and 2. In both experiments, cows were assigned randomly to treatments in a replicated 3 × 3 Latin square design. Periods in both studies were 21 d with the first 14 d for adaptation and the last 7 d as the sampling period. Cows were allocated to squares according to their lactation number and milk production. Two squares consisted of primiparous cows, and the other square contained multiparous cows. For experiment 1, the primiparous cows averaged 78 ± 17 DIM and the multiparous cows averaged 125 ± 21 DIM. In experiment 2, the primiparous and the multiparous cows averaged 143 ± 17 and 190 ± 21 DIM, respectively.

Treatments in experiment 1 were direct-cut forage (**FF**) without grain supplementation (**FF0**), FF plus 10 kg DM of concentrate based on finely ground dry shelled corn (**DCF**), and FF plus 10 kg DM of concentrate based on coarsely ground high moisture ear corn (**HMC**). In experiment 2, treatments were DCF, HMC, and **HMF** (FF plus 10 kg DM of concentrate based on high moisture ear corn finely ground). Coarsely ground, high moisture ear corn was stored in an oxygen limiting silo and finely ground high moisture ear corn was obtained by roller milling the coarsely ground high moisture ear corn. Geometric mean diameters (mm) for corn particles were 1.25, 3.14, and 2.22 for DCF, HMC, and HMF, respectively (Ensor et al., 1970).

Forage was offered ad libitum four times per day in both experiments. At 1700 h the first meal of fresh forage was offered, and the remaining forage was placed in mesh bags and stored in a 4°C cooler. Cows were offered refrigerated forage at 2300, 0500, and 1100 h. Before every feeding of new forage, mangers were cleaned. For experiment 1, concentrates were divided into two equal portions and fed as a top dress at 1900 and 0700 h. Fifty grams of a mineral mix was put inside the rumen of cows on the FF0 treatment at the same time of each concentrate feeding. For experiment 2, the supplements were divided in four equal portions and fed as a top dress at time of forage feeding.

Sampling, Laboratory Analysis, and Calculations

Fresh forage, concentrates, and orts from each cow were sampled daily. Samples were dried in a 60°C forced air oven for 72 h and ground through a 2-mm screen in a Wiley mill (Arthur H. Thomas, Philadelphia, PA) before laboratory analysis. Forage and concentrate samples were analyzed for DM, OM, CP (AOAC, 1990) and for NDF and ADF (Van Soest et al., 1991). Composite samples of concentrates, forage, and feces for each period also were analyzed for starch plus free glucose (**SFG**) by endoamylase and exoglucosidase incubation before a glucose oxidase assay was used (Herrera-Saldana et al., 1990). Composition of forage and concentrates is summarized in Table 1.

Milk production was recorded daily and production on the last 6 d of each period and milk composition for the last four consecutive milkings were used for statistical analyses. Individual a.m. and p.m milk samples were analyzed for fat, crude protein, and SNF (Wisconsin DHI Cooperative Center, Appleton, WI). Yields of SCM and energy output in milk corrected for BW change (**EM**) were calculated based on Tyrell and Reid (1965). Milk samples also were collected at each of the last four milkings of each period and were analyzed to determine MUN concentrations as described in Reis and Combs (2000).

Ruminal DM degradation of direct-cut forage and concentrates were evaluated by an in situ technique (Ørskov et al., 1980), starting on d 17 of each period during experiment 1. Forage samples were collected immediately before the sampling phase of each experimental period. The samples were frozen and ground with dry ice in a chilled Wiley mill grinder through a 4-mm screen. Concentrates were ground through a 2-mm screen in the same grinder. Dacron bags (9 × 15 cm and 52 μ pore size) were filled with 6 g DM of either fresh forage or concentrate and were placed in the rumens of six cannulated cows. All bags plus blanks, in duplicates, were inserted into the six cows at the same time and pairs of bags were sequentially removed at 3, 6, 12, 18, 24, 48, 72, and 96 h of incubation. Upon removal from the rumen, bags were soaked immediately in cold water, frozen, and subsequently washed in a washing machine (model A5460XTW, Whirlpool Corporation, Benton Harbor, MI) at the end of the

Table 1. Nutrient composition[1] of direct-cut forage and concentrates used in experiments 1 and 2.

Item	DM	OM	CP	NDF	ADF	SFG[2]
	(%)	(% of DM)				
Direct cut forage						
Experiment 1						
Period 1	21.4 ± 1.1	90.0 ± 0.8	17.7 ± 1.1	39.6 ± 3.5	28.1 ± 2.4	17.5 ± 1.7
Period 2	18.2 ± 1.2	88.0 ± 0.5	22.3 ± 1.3	36.1 ± 2.4	21.4 ± 2.3	15.1 ± 1.3
Period 3	22.4 ± 1.9	89.0 ± 0.6	22.9 ± 1.0	34.1 ± 2.5	22.8 ± 1.6	14.2 ± 1.2
Experiment 2						
Period 1	24.7 ± 1.0	89.9 ± 0.9	21.0 ± 1.0	36.4 ± 1.5	26.4 ± 1.2	12.5 ± 1.5
Period 2	26.4 ± 1.1	89.0 ± 0.8	20.4 ± 1.1	36.7 ± 1.2	25.1 ± 2.0	12.1 ± 1.5
Period 3	23.1 ± 1.7	89.4 ± 0.7	24.0 ± 1.0	36.2 ± 1.2	25.4 ± 1.7	12.2 ± 0.3
Concentrates[3]						
DCF	90.5	96.1	12.0	11.4	2.2	75.6
HMC	75.3	96.5	12.1	12.8	4.3	72.8

[1]Mean ± SD.

[2]Starch plus free glucose.

[3]DCF = Dry shelled corn-based concentrate, HMC = high moisture ear corn-based concentrates.

trial. Zero hour bags were soaked in warm water and washed with the other bags in the same washing machine cycle. Empty bags and bags with residue were dried at 60°C for 72 h for DM determination. Within each cow, residual DM at each incubation time were fitted with a nonlinear procedure of Multivariant secant of false position (DUD) method (SAS, 1989) and fitted to a first-order kinetic model with an indigestible fraction and a discrete lag time before digestion (Mertens and Loften, 1980). Forage and grain DM were divided into three pools by the kinetic model: 1) a soluble fraction of DM that is assumed to be instantaneously degraded in the rumen (fraction A), 2) a slowly degraded fraction (fraction B) that degrades at a constant fractional rate (k), and 3) an undegradable fraction (fraction C).

Ytterbium was used as an external marker to measure apparent total tract digestibility. Seventeen grams of $YbCl_3$ was diluted in 15 L of distilled water to obtain a final solution concentration of 702 mg of Yb/L. This solution was infused into the rumen with a variable speed peristaltic pump (VSP 12, Pulsafeeder Inc., Punta Grande, FL) for 20 h/d, from d 11 through 21 of each period. Flow for each pump was tested at the end of each period to calculate the ytterbium dosage rate.

Ruminal liquid, grain, and forage turnover were estimated with cobalt-EDTA, lanthanum, and chromium-mordanted fiber as markers, respectively. Cobalt-EDTA and chromium-mordanted fiber were prepared according to Udén et al. (1980), and lanthanum marker was prepared as in Hartnell and Satter (1979). Ten grams of cobalt-EDTA, 500 g of grain labeled with 1 g of lanthanum, and 20 g of chromium-mordanted fiber were pulse-dosed into the rumen at 1400 h on d 17 of each period and mixed with ruminal contents. Fecal grab samples were taken at 0, 6, 12, 18, 24, 36, 48, 60, 72, 84, and 96 h after the marker pulse dose to determine rate of passage and apparent total tract digestibility as in Reis and Combs (2000).

Ruminal fluid (100 ml) was collected at 1900 h on d 16 of each period immediately before concentrate feeding. This sample was considered 0 h, and additional samples were collected at 2, 3, 6, 9, 12, 14, 15, 18, 21, and 24 h thereafter. Samples were analyzed for pH and ammonia as in Reis and Combs (2000). Samples for VFA determination were prepared differently in experiments 1 and 2. For experiment 1, a 15-ml aliquot of rumen fluid was acidified with 0.3 ml of 50% H_2SO_4 (vol/vol) and in experiment 2, a 15-ml aliquot of rumen fluid was acidified in a 1:1 ratio (vol/vol) with undiluted formic acid. Volatile fatty acids were determined according to Brotz and Schaefer (1987) by GLC (Varian 2100, Sunnyvale, CA) with GP 10% SP-1200/1% H_3PO_4 on 80/100 chromasorb W AW column packing (Supelco, Inc., Bellefonte, PA) and corrected for recovery with an internal standard (2-ethyl butyrate).

Volume and wet weight of the ruminal contents were determined by emptying rumens of each cow into tared 70-L barrels before 1200 h on d 21 of each period. Approximately 10% of the ruminal contents were separated during the evacuation process, and 400-g subsamples were dried at 60°C for 72 h for DM determination of rumen contents.

Urine samples were obtained from each cow during d 18 of each period. Purine derivatives excreted in urine were used to indirectly estimate ruminal microbial protein synthesis (Broderick and Merchen, 1992). A 5-ml aliquot of urine was diluted to 50 ml with 0.036 N H_2SO_4 solution and stored at −20°C. At the end of the trial, samples were analyzed for allantoin according to Fujihara et al. (1987) and creatinine according to Oser (1965).

A parallel in vitro study was conducted to compare the directly measured DMI to intakes indirectly estimated by indigestible ADF. Feeds and individual fecal composite samples were incubated in vitro in rumen fluid for 144 h and then analyzed for indigestible ADF (Craig et al., 1984). Indigestible ADF was used as an internal marker to determine DM, OM, forage, NDF, ADF, and SFG intakes.

Statistical Analyses

Data were analyzed using the mixed model procedure of SAS 6.12 for a Latin square design (Proc Mixed; SAS, 1996). The following model was fitted to the data for all variables that did not have repeated measurements over time: $Y_{ijkl} = \mu + S_i + P_j + V_{k(i)} + T_1 + ST_{il} + PT_{jl} + E_{ijkl}$, where Y_{ijkl} = dependent variable, μ = overall mean, S_i = effect of square I, P_j = effect of period j, $V_{k(i)}$ = effect of cow k (within square i), T_1 = effect of treatment l, ST_{il} = interaction between square i and treatment l, PT_{jl} = interaction between period j and treatment l, and E_{ijkl} = residual error. All terms were considered fixed except $V_{k(i)}$ and E_{ijkl}, which were considered random.

The following model was used for ruminal variables that had repeated measurements over time (pH, ammonia, acetate, propionate, butyrate, total VFA, acetate:propionate ratio): $Y_{ijklm} = \mu + S_i + P_j + V_{k(i)} + T_1 + PT_{(jl)} + E_{lijkl} + Z_m + ZT_{ml} + E_{2ijklm}$, where Y_{ijklm} = dependent variable, μ = overall mean, S_i = effect of square i, P_j = effect of period j, $V_{k(i)}$ = effect of cow k within square i, T_1 = effect of treatment l, $PT_{(jl)}$ = effect of the interaction among period j and treatment l, E_{lijkl} = whole plot error, Z_m = effect of time m, ZT_{ml} = interaction between time m and treatment l, and $E_{2ijklm}\cdot$ = sub plot error.

All terms were considered fixed, except for $V_{k(i)}$, E_{1ijkl}, and E_{2ijklm} which were considered random. The interaction S*T was removed from the model because of lack of significance ($P > 0.05$) for all variables.

The main effects of corn supplementation, source of corn, and fineness of grind were tested by orthogonal contrasts. The effect of corn particle size was tested in experiment 2 by the contrast between HMC and HMF. Significant differences were declared at $P < 0.05$ and tendencies were noted if $P \geq 0.05$ and < 0.10.

RESULTS AND DISCUSSION

Forage and Concentrate Composition

Direct-cut forage contained high concentrations of CP throughout both experiments, with lower concentrations during the first period of experiment 1 (Table 1). The highest concentrations of forage NDF and ADF also were observed during the first period of experiment 1. The SFG concentration of the DCF supplement was higher than in the HMC concentrate (75.6 vs. 72.8%, respectively). The HMC supplement was higher in ADF due to presence of cobs.

High yielding dairy cows require diets that contain 16 to 18% CP on a DM basis, and the RUP should constitute about 37 to 38% of the total protein (NRC, 1989). The diets of cows on the FF0 treatment in experiment 1 contained more total CP than the cows required (Table 2). Because the CP in fresh forage is 75 to 80% soluble, and approximately 90% of it is degraded in the rumen (Kolver et al., 1998), these diets appear to be deficient in RUP.

Milk Production and Composition

Experiment 1. Yields of milk, SCM, and milk protein increased with grain supplementation, but were not affected by source of corn (Table 3). Milk fat percentage and MUN were reduced, while milk protein percentage increased when grain was fed. The percentage of SNF and protein yield increased, and milk protein percentage tended to increase ($P = 0.09$) with grain supplementation. Milk fat percentage, MUN, and milk protein percentage were not affected by source of corn. Corn supplementation, but not source of corn, increased milk protein production and milk protein percentage. Milk production responses to grain supplementation in experiment 1 were 0.47 kg of milk/kg of concentrate offered. Kellaway and Porta (1993) summarized several short-term experiments and reported that the typical response to concentrate supplementation in cattle grazing high quality pasture ranged from 0.6 to 1.2 kg of milk/kg of extra supplement fed. Reis and Combs (2000) reported that cattle grazing immature alfalfa-grass pasture produced an additional 0.86 kg of milk/kg of additional corn-based supplement. Bargo et al. (1998) and Soriano et al. (1998) found no differences in milk production of grazing cows due to corn moisture content. Corn particle size also was reported to have little effect on milk production of confined cattle (Knowlton et al., 1998). However, Knowlton et al. (1996) observed an increase in milk protein percentage and Ekinci and Broderick (1997) noted that yield of milk protein increased due to fine grinding of corn.

The increase in the production of milk and the level of SNF due to grain supplementation compensated for the drop in milk fat, therefore SCM production was higher for supplemented cows than cows fed FF0. Solids-corrected milk is a more appropriate way of evalu-

Table 2. Composition of diets for experiments 1 and 2.[1]

	Experiment 1			Experiment 2		
	DCF	HMC	FFO	DCF	HMC	HMF
Ingredients, % of DM						
Forage, direct cut	53.5	54.1	99.4	52.5	49.9	50.3
Dry shelled corn, finely ground	43.3	. . .	. . .	44.3	. . .	. . .
High moisture ear corn, coarsely ground	. . .	41.9	. . .	. . .	45.7	. . .
High moisture ear corn, finely ground	. . .	. . .	. . .	. . .	. . .	45.4
Soybean meal	2.55	3.40	. . .	2.60	3.70	3.70
Dicalcium phosphate	0.15	0.14	0.14	0.14	0.16	0.14
Limestone	0.27	0.27	0.25	0.25	0.29	0.25
Mineral and vitamin supplement[2]	0.23	0.23	0.21	0.21	0.25	0.21
Nutrient content of diets						
DM, %	50.2	42.6	20.7	52.7	53.5	46.3
OM, % of DM	97.1	95.6	89.0	89.3	88.5	88.9
CP, % of DM	17.1	17.9	21.0	16.4	16.0	16.4
RUP, % of CP	35.0	33.5	32.0	35.2	35.1	33.8
NDF, % of DM	25.3	25.1	36.6	23.6	22.9	23.0
ADF, % of DM	14.8	15.1	24.1	14.3	13.6	14.1
SFG, % of DM[3]	43.7	41.7	15.6	38.8	39.5	38.2
NEL, Mcal/kg DM[4]	1.69	1.67	1.43	1.58	1.58	1.54

[1]FFO = Direct-cut grass-legume forage (FF) with no supplementation; DCF = FF plus 10 kg DM of concentrate based on ground, dry shelled corn; HMC = FF plus 10 kg DM of concentrate based on high moisture ear corn, coarsely ground; HMF = FF plus 10 kg DM of concentrate based on high moisture ear corn, finely ground.

[2]Mineral mix = Chloride 61%, sodium 39, and (per kg) cobalt > 20 mg, copper > 1400 mg, iron > 3450 mg, iodine > 80 mg, manganese > 5500 mg, selenium > 360 mg, zinc > 5500 mg, vitamin A > 7,000,000 IU, vitamin D_3 > 2,250,435 IU, and vitamin E > 1827 IU.

[3]Starch plus free glucose.

[4]Calculation of NE_L, Mcal/kg DM = (1.0055 – 0.0098*%NDF)/0.454 for direct-cut forage based on Mertens (1983) and feed composition tables (NRC, 1989) for concentrates.

ating milk production responses to grain than FCM, which adjusts primarily fat and total production. The gross efficiency of production, measured as kilograms of SCM produced per kilograms of DMI, was higher for nonsupplemented cows than for cows fed HMC. Careful interpretation of this data is urged because cows on FFO utilized significantly more body reserves (Table 4; $P < 0.01$) to achieve this level of production. Grain supplementation tended to increase EM production ($P = 0.07$).

A reduction in MUN with treatments DCF and HMC relative to FFO suggests that ammonia utilization was improved when cows were supplemented with grain. In experiment 1, grain supplementation reduced forage N intake (Table 4) and provided an additional source of ruminally fermentable carbohydrate. Because cows on DCF consumed more SFG than cows on HMC in experiment 1, it is unclear whether the source of corn had an impact on MUN.

Experiment 2. Milk production and milk composition were not affected by source of corn or fine grinding of the corn supplement. Milk yields were 27.5, 25.9, and 26.1 kg/d for DCF, HMC, and HMF, respectively. Milk protein percentage and protein yield tended to increase ($P = 0.10$; $P = 0.07$, respectively), when HMF was fed compared to HMC. Milk urea nitrogen was significantly lower, with the dry corn treatment compared to the high moisture ear corn treatments ($P < 0.01$). Intakes of SFG were again higher on DCF than the treatments containing high moisture grain. A reduction in particle size of the high moisture grain treatment did not affect MUN.

Feed Intake and Nutrient Digestibilities

Experiment 1. Intakes of DM, OM, direct-cut forage, NDF, and ADF were affected by supplementation, but not by source of corn (Table 4). Digestibilities of DM, OM, NDF, and ADF were not affected by treatment. However, there was a tendency for higher DM and OM digestibility for supplemented cows compared with cows on FF0. Supplementation increased ($P < 0.01$) total intake, digestibility, and fecal outputs of SFG. The digestibility of SFG was not affected by the source of corn. Excretion of urinary allantoin was higher ($P < 0.01$) in cows fed DCF and HMC than FF0 diets; however, no differences within type of concentrate were observed. Blood allantoin concentrations were similar across treatments. Ratios of urinary allantoin to creatinine were higher for supplemented treatments ($P < 0.01$) than for FF0. Urinary allantoin to creatinine ratios also were higher in cows fed DCF than HMC.

In experiment 1, we used indigestible ADF to estimate DMI and compared these results to our direct measurements of intake (Table 4). Neither technique would suggest that the form of corn in the concentrate affected intake and digestibility of DM and OM. The indigestible ADF procedure, however, underestimated observed intake of cows fed FFO by 10 to 15% and cows fed the grain supplements by 2 to 8%. This underestimation of intake resulted in lower estimates of digestibility when the marker technique was used and would lead one to conclude that grain supplements had a greater impact on digestibility than if intake were measured directly (Table 4).

In experiment 1, supplemented and unsupplemented cows consumed, on average, 3.40 and 2.70% of their BW as DM, respectively. Each kilogram of concentrate fed increased daily DMI by 0.3 kg, and decreased forage DMI by 0.65 kg. Kellaway and Porta (1993) reported that, in general, pasture DMI decreases about 0.5 to 0.9 kg for each kilogram of additional grain fed to cattle grazing high quality pasture. The lower response in milk yield (Table 3) and total DMI (Table 4) to grain supplements compared to grazing cattle may reflect a higher rate of forage intake when cattle are fed fresh forage in confinement than when allowed to graze. Reis and Combs (2000) and Depies (1994) reported that cattle producing similar amounts of milk and grazing pastures that were similar in botanical and nutrient composition to the forage fed in this experiment consumed about one kilogram less forage DM per day than cows in the experiments reported herein. No differences in total DMI as a consequence of source of corn were reported with grazing

Table 3. Milk production and milk composition of cows fed various concentrates and direct-cut grass-legume forage.

	Treatments[1]					Contrasts, P	
Item	DCF	HMC	FFO	SEM	Trt P	DCF and HMC vs. FFO	DCF vs. HMC
Experiment 1							
Milk, kg/d	30.7[a]	29.9[a]	25.6[b]	1.3	0.02	0.01	0.53
4% FCM, kg/d	26.4	27.1	25.0	1.5	0.31	0.16	0.66
SCM, kg/d	26.6	26.1	24.5	1.4	0.08	0.03	0.56
EM, Mcal/d[2]	42.4	39.1	34.3	1.7	0.13	0.07	0.32
Fat, %	3.15	3.25	3.77	0.20	0.09	0.04	0.72
Fat, kg/d	0.96	0.98	0.98	0.07	0.96	0.90	0.81
Protein[4], %	3.36	3.35	3.14	0.07	0.09	0.04	0.96
Protein[4], kg/d	1.03[a]	1.02[a]	0.79[b]	0.04	0.01	0.01	0.63
SNF, %	9.00[a]	8.95[a]	8.57[b]	0.09	0.01	0.02	0.69
MUN, mM	3.25[b]	3.90[ab]	5.26[a]	0.42	0.04	0.02	0.32
Milk/DMI, kg/kg	1.46	1.54	1.69	0.09	0.29	0.14	0.56
SCM/DMI, kg/kg	1.53[ab]	1.35[b]	1.61[a]	0.09	0.02	0.04	0.09
EM/DMI, kg/kg	2.30	1.97	1.67	0.08	0.18	0.12	0.23
Experiment 2							
Item	DCF	HMC	HMF	SEM	Trt P	DCF vs. HME[3]	HMC vs. HMF
Milk, kg/d	27.5	25.9	26.1	1.6	0.38	0.18	0.87
4% FCM, kg/d	26.2	24.8	25.9	1.7	0.56	0.33	0.52
Fat, %	3.63	3.69	3.56	0.18	0.55	0.53	0.34
Fat, kg/d	1.01	0.96	0.99	0.16	0.64	0.99	0.39
Protein[4], %	3.52	3.49	3.61	0.09	0.22	0.49	0.10
Protein[4], kg/d	0.96	0.90	0.99	0.04	0.15	0.64	0.07
SNF, %	9.16	9.09	9.00	0.17	0.71	0.51	0.64
SNF, kg/d	2.51	2.35	2.36	0.15	0.45	0.22	0.94
MUN, mM	4.08[b]	4.94[a]	4.84[a]	0.37	0.03	0.01	0.70
FCM/DMI, kg/kg	1.25	1.25	1.21	0.07	0.44	0.41	0.29

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

[1]FFO = Direct cut grass-legume forage (FF) with no supplementation; DCF = FF plus 10 kg DM of concentrate based on ground, dry shelled corn; HMC = FF plus 10 kg DM of concentrate based on high moisture ear corn-coarsely ground; HMF = FF plus 10 kg DM of concentrate based on high moisture ear corn-finely ground.

[2]EM Mcal/d = energy output in the milk corrected for body weight changes.

[3]High moisture ear corn (HMC and HMF).

[4]Total CP in milk.

Table 4. Body weight change, feed intake, nutrient digestibilities, and urine constituents of cows fed various concentrates and direct-cut grass-legume forage (experiment 1).

	Treatments[1]					Contrasts, P	
	DCF	HMC	FFO	SEM	Trt P	DCF and HMC vs. FFO	DCF vs. HMC
BW change, kg/period	–6.51[at]	3.28[b]	–16.6[a]	3.8	0.01	0.01	0.08
Intake, kg/d							
DM[2]	20.7[a]	20.3[a]	17.8[b]	0.3	0.01	0.01	0.23
OM	20.1[a]	19.4[a]	16.1[b]	0.4	0.01	0.01	0.11
Forage DM[2]	11.1[b]	10.9[b]	17.8[a]	0.4	0.01	0.01	0.73
DM[3]	20.0[a]	19.4[a]	15.4[b]	0.7	0.01	0.01	0.30
Forage DM[3]	9.9[b]	9.4[b]	15.4[a]	0.7	0.01	0.01	0.40
NDF	5.2[b]	5.1[b]	6.3[a]	0.2	0.02	0.01	0.39
ADF	3.1[b]	3.1[b]	4.4[a]	0.1	0.01	0.01	0.93
SFG[4]	9.1[a]	8.5[b]	2.8[c]	0.1	0.01	0.01	0.01
Digestibility, %							
DM[2]	70.5	68.2	60.6	2.0	0.15	0.08	0.47
DM[3]	67.4[a]	66.9[a]	55.9[b]	1.8	0.03	0.01	0.87
OM[2]	72.8	71.3	63.6	2.0	0.17	0.09	0.65
NDF[2]	48.3	45.8	44.2	3.1	0.78	0.60	0.65
ADF[2]	40.4	41.0	40.3	3.5	0.99	0.94	0.93
SFG[2]	92.8[a]	88.8[a]	79.9[b]	1.1	0.03	0.01	0.10
Fecal SFG, %	10.7[b]	15.0[a]	8.0[c]	0.9	0.01	0.01	0.05
Blood and Urine, m*M*							
Blood allantoin	0.33	0.32	0.29	0.27	0.13	0.18	0.09
Urine allantoin (UA)	17.4[a]	15.8[a]	7.77[b]	1.91	0.01	0.01	0.36
Urine creatinine (UC)	6.30	6.96	4.43	0.65	0.07	0.04	0.50
UA:UC ratio	2.97[a]	2.36[b]	1.75[c]	0.14	0.01	0.01	0.01

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

[1]FFO = Direct-cut grass-legume forage (FF) with no supplementation; DCF = FF plus 10 kg DM of concentrate based on ground, dry shelled corn; HMC = FF plus 10 kg DM of concentrate based on high moisture ear corn, coarsely ground; HMF = FF plus 10 kg DM of concentrate based on high moisture ear corn, finely ground.

[2]Calculations based on direct measurement of DMI.

[3]Calculations based on indigestible ADF as an internal marker for estimating DMI.

[4]Starch plus free glucose.

cattle (Soriano, 1998) or confined cattle fed TMR diets (Wilkerson et al., 1997).

In experiment 1, cows fed DCF consumed 580 g more SFG than did cows supplemented with HMC (Table 4). Cows fed DCF had lower fecal SFG concentrations than cows fed HMC (Table 4; $P < 0.05$). The amount of SFG apparently digested was 8.40 and 7.52 kg/d for treatments DCF and HMC, respectively. However, milk and SCM production were similar for treatments DCF and HMC.

The urinary allantoin to creatinine ratios in experiment 1 suggest that ruminal microbial growth was higher for the grain-supplemented cows than for cows fed FF0, and that cows fed DCF produced more microbial protein than cows fed HMC. This probably reflects the higher intake of SFG with DCF and is consistent with changes in MUN discussed previously.

Experiment 2. Intake and digestibility of DM, OM, NDF, and ADF were not affected by corn source or corn particle size (Table 5). Fecal SFG was reduced by fine-grinding high moisture ear corn ($P < 0.01$). Although there was a significant difference in SFG intake in experiment 2 between DCF and the diets containing high moisture corn (Table 5), the amounts of SFG apparently digested (6.88, 6.43, and 6.82 for treatments DCF, HMC, and HMF, respectively) were similar among treatments. There was a trend (P = 0.07) for increased SFG digestibility due to a reduction in particle size of the high moisture ear corn (87.4 and 92.4% for HMC and HMF, respectively). Knowlton et al. (1996) observed an increase in starch digestibility due to a reduction in particle size of dry corn and Ekinci and Broderick (1997) improved starch utilization by grinding high moisture ear corn. This suggests that corn particle size ($P < 0.01$) was important in reducing fecal starch excretion.

The allantoin to creatinine ratio tended to be higher (P = 0.07) for HMF than with HMC, which suggests that ruminal microbial growth was improved by fine-grinding the high moisture corn. Concentrations of MUN did not change due to fine grinding of the high moisture corn (Table 3).

Ruminal Fermentation and Physical Characteristics

Experiment 1. Weight and volume of ruminal digesta were not affected by concentrate supplementation or source of corn (Table 6). Ruminal digesta DM content was significantly higher ($P < 0.01$) for supplemented cows than for cows on FF0. Higher ruminal DM concentration for supplemented cows was expected because the proportion of concentrate in the diets represented almost 50% of DMI. This would be expected to reduce rumination and eating activity and, therefore, saliva production. Mean ruminal pH, molar concentrations of acetate, propionate, butyrate, and acetate to propionate ratio were affected by supplementation ($P < 0.01$) but not by source of the corn grain.

The rapid drop in ruminal pH after grain feeding in experiment 1 (Figure 1) indicated that both supplements were fermented rapidly in the rumen. There was no difference in mean ruminal pH due to the type of corn in the concentrate. This observation is consistent with results of Soriano (1998). The pH values remained below 6.0 at most sampling times for supplemented cows, and the lowest value was 3 h after the 1900 h concentrate feeding. This greater decline in ruminal pH could be influenced not only by concentrate fermentation but also by the fermentation of the forage, because the 1700 h meal was the meal at which the animals consumed the greatest amount of forage DM. A similar pattern, although less pronounced, was observed after the 0700 h concentrate feeding. During the night, all treatments showed significantly lower average ruminal pH compared with the daytime measurements. Soriano (1998) reported that the lowest ruminal pH occurred 8 h after supplementing cows that were either grazing or fed fresh forage with high starch concentrates. Reductions in ruminal pH often have been cited as the major cause of depressed fiber digestion, but this may not always explain reductions in intake and digestibility. In this study, the reduced ruminal pH of supplemented cows did not affect either DMI or digestibility. Comparing our results (Table 6) with those reported by Reis and Combs (2000), it appears that the ruminal pH of lactating cows fed indoors with fresh forage tended to be lower compared with grazing cows for the same levels and type of concentrate supplementation. This could be due to the differences in meal patterns, salivation, or forage intake. Low ruminal pH has been associated with high VFA concentrations and inadequate physically effective fiber in the diet or with the r buffering capacity of the forage.

Table 5. Feed intake, nutrient digestibilities, and urine constituents of cows fed various concentrates and direct-cut grass-legume forage (experiment 2).

	Treatments[1]					Contrasts, *P*	
	DCF	HMC	HMF	SEM	Trt *P*	DFC vs. HME[2]	HMC vs. HMF
Intake, kg/d							
DM	20.6	19.9	20.0	0.7	0.55	0.31	0.83
OM	19.1	18.4	18.6	0.6	0.62	0.37	0.82
NDF	5.1	4.8	4.8	0.2	0.56	0.32	0.84
ADF	3.0	2.9	2.9	0.2	0.83	0.59	0.85
SFG	7.9[a]	7.4[b]	7.4[b]	0.1	0.01	0.01	0.83
Digestibility,[3] %							
DM	73.6	73.4	74.6	1.9	0.71	0.83	0.55
OM	67.6	69.8	72.7	1.6	0.22	0.17	0.24
NDF	40.8	41.5	40.8	1.5	0.92	0.85	0.74
ADF	35.7	36.8	34.9	2.3	0.79	0.96	0.55
SFG	87.3	87.4	92.4	1.2	0.11	0.19	0.07
Fecal SFG,[4] %	13.1[a]	14.0[a]	9.4[b]	0.6	0.01	0.08	0.01
Urine constituents, m*M*							
Allantoin (UA)	17.1	16.3	17.1	1.3	0.68	0.68	0.48
Creatinine (UC)	6.55	6.69	5.37	0.63	0.19	0.41	0.10
UA:UC ratio	2.60	2.60	3.13	0.18	0.13	0.22	0.07

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

[1]FFO = Direct-cut grass-legume forage (FF) with no supplementation; DCF = FF plus 10 kg DM of concentrate based on ground, dry shelled corn; HMC = FF plus 10 kg DM of concentrate based on high moisture ear corn-coarsely ground; HMF = FF plus 10 kg DM of concentrate based on high moisture ear corn-finely ground.

[2]High moisture ear corn (HMC and HMF).

[3]Digestibility estimated using direct measurement of intake.

[4]Starch plus free glucose.

Table 6. Physical characteristics of ruminal digesta and ruminal fermentation measurements of cows fed various concentrates and direct-cut grass-legume forage.

	Treatments[1]					Contrasts, P	
Item	DCF	HMC	FFO	SEM	Trt P	DCF and HMC vs. FFO	DCF vs. HMC
Experiment 1							
Digesta							
Weight, kg	68.0	69.8	72.2	3.5	0.48	0.29	0.61
Volume, L	81.8	84.3	88.6	5.5	0.33	0.18	0.56
Density, kg/L	0.83	0.83	0.82	0.02	0.92	0.72	0.88
DM, %	14.1[a]	14.9[a]	12.6[b]	0.0	0.01	0.01	0.06
Rumen fluid							
pH	5.68[b]	5.71[b]	6.06[a]	0.04	0.01	0.01	0.60
Ammonia, m*M*	9.7[b]	11.5[b]	20.7[a]	0.9	0.01	0.01	0.12
Acetate (A), m*M*	70.3[b]	75.6[b]	84.6[a]	2.7	0.01	0.01	0.18
Propionate (P), m*M*	40.2[a]	39.7[a]	24.2[b]	1.4	0.01	0.01	0.81
Butyrate, m*M*	15.8[a]	14.1[ab]	13.2[b]	0.5	0.01	0.01	0.08
Total VFA, m*M*	133.6	137.4	129.0	3.7	0.31	0.18	0.47
A:P ratio	1.78[b]	1.97[b]	3.54[a]	0.10	0.01	0.01	0.11
	DCF	HMC	HMF	SEM	Trt P	DCF vs. HME[2]	HMC vs. HMF
Experiment 2							
Digesta							
Weight, kg	68.2	72.2	72.7	3.4	0.22	0.10	0.85
DM, %	14.5[b]	15.7[a]	14.5[b]	0.3	0.01	0.04	0.01
Rumen fluid							
pH	5.84	5.85	5.87	0.05	0.73	0.57	0.59
Ammonia, m*M*	8.5[b]	10.2[a]	8.9[ab]	0.7	0.1	0.08	0.06
Acetate (A), m*M*	82.9	84.0	82.4	1.0	0.44	0.80	0.22
Propionate (P), m*M*	40.1	40.3	41.5	2.3	0.80	0.70	0.59
Butyrate, m*M*	15.2	14.2	15.0	0.5	0.29	0.28	0.24
Total VFA, m*M*	144.1	144.8	145.2	2.6	0.91	0.70	0.87
A:P ratio	2.17	2.16	2.04	0.13	0.63	0.61	0.42

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

[1]FFO = Direct-cut grass-legume forage (FF) with no supplementation; DCF = FF plus 10 kg DM of concentrate based on ground, dry shelled corn; HMC = FF plus 10 kg DM of concentrate based on high moisture ear corn-coarsely ground; HMF = FF plus 10 kg DM of concentrate based on high moisture ear corn-finely ground.

[2]High moisture ear corn (HMC & HMF).

The daily pattern of ruminal ammonia and VFA concentrations followed the forage-feeding pattern (Figure 1). Higher ruminal ammonia and VFA concentrations were noted in the late afternoon and the first half of the evening, and could be because of higher forage intake at the 1700 h-meal than at any other time. The ruminal ammonia concentration for unsupplemented cows (mean 20.7 m*M*) was significantly higher at every time point of the day (Figure 1) and increased at every forage meal, with the exception of the 0500 h feeding. The decrease in ruminal ammonia concentrations with grain feeding was consistent with the lower concentrations of MUN and urinary allantoin observed in this experiment and reported by Carruthers et al. (1997).

Grain supplementation reduced ruminal ammonia concentration, probably due to decreased forage intake and increased microbial protein synthesis in the rumen. No differences in mean ruminal pH were reported by Soriano (1998) with lactating dairy cows under rotational grazing when cows were supplemented with ground, high moisture shelled corn or ground, dry shelled corn fed in different amounts and in different particle sizes. Additionally, Bargo et al. (1998) found no difference in ruminal pH when lactating dairy cows were fed ground, dry corn, or steam flaked corn.

Experiment 2. Dry matter content of ruminal digesta was significantly higher ($P < 0.04$) for the diets containing high moisture corn than for DCF (Table 6). The concentration of ruminal ammonia was higher for diets supplemented with high moisture corn than for DCF. Treatment contrasts indicated that both source of corn and particle size tended to affect ruminal ammonia concentration ($P = 0.08$ and $P = 0.06$, respectively). Acetate to propionate ratio was not affected by source of corn or particle size of corn in the concentrate.

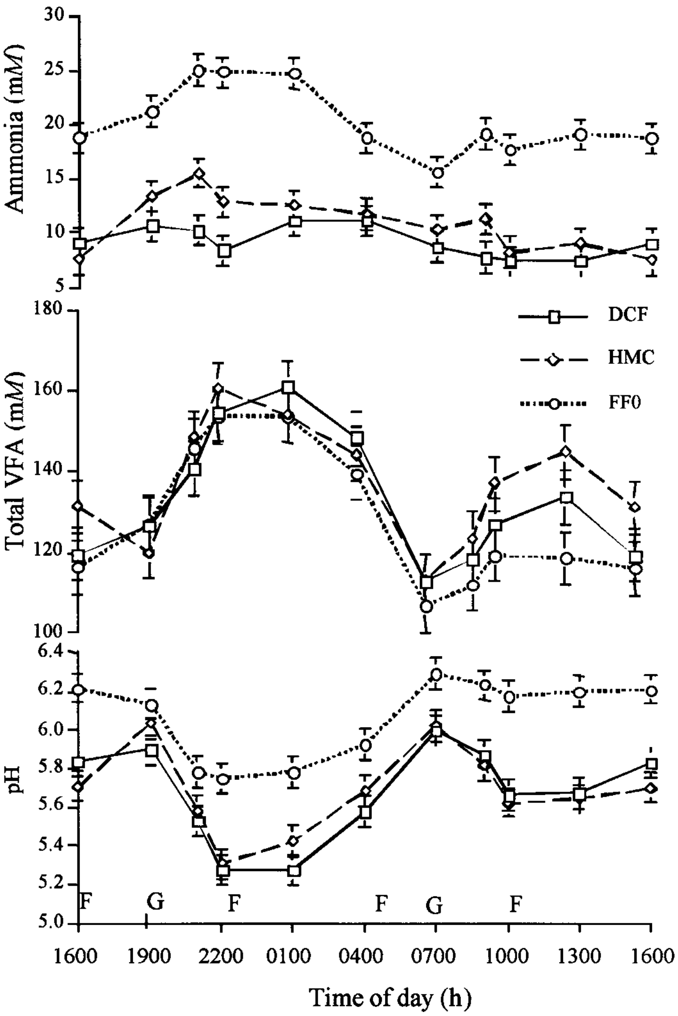

Figure 1. Daily pattern of ruminal ammonia, total VFA, and pH of cows fed ad libitum direct-cut grass-legume forage with no grain supplement (FFO), or with 10 kg/d of concentrate based on either ground high moisture corn (HMC) or ground dry shelled corn (DCF) in Experiment 1. Vertical bars are SE of treatment mean. Forage feeding times (F) and grain feeding times (G) are indicated on the x axis.

Mean ruminal pH, individual VFA concentrations, and total VFA concentration were not affected by treatment.

In experiment 2, corn particle size and source of corn had no effect on ruminal pH throughout the day (Figure 2). The lowest pH for all treatments was recorded between 6 and 9 h after the 1800 h feeding. The peak concentrations of VFA were also between 6 and 9 h after the 1800 h feeding, and this corresponds to when the lowest ruminal pH was observed.

If the ruminal pH measurements for DCF and HMC for experiments 1 and 2 are compared, mean ruminal pH appeared to be consistently lower throughout the day in experiment 1. Cows consumed approximately 1.1 kg/d more SFG when fed treatments DCF and HMC in experiment 1 than in experiment 2. Cows were also fed grain twice daily in the first study and four times daily in the second experiment. It is not clear whether frequency of supplement feeding or the reduction in SFG intake accounted for the lower ruminal pH in the experiment 1.

Ruminal Degradation of Forage and Concentrate

Experiment 1. Neither grain supplementation nor source of corn affected the rates of passage of forage, liquid, or grain (Table 7). Grain supplementation also did not affect pool sizes of fractions A and B, lag time, or the proportion of forage DM degraded in the rumen

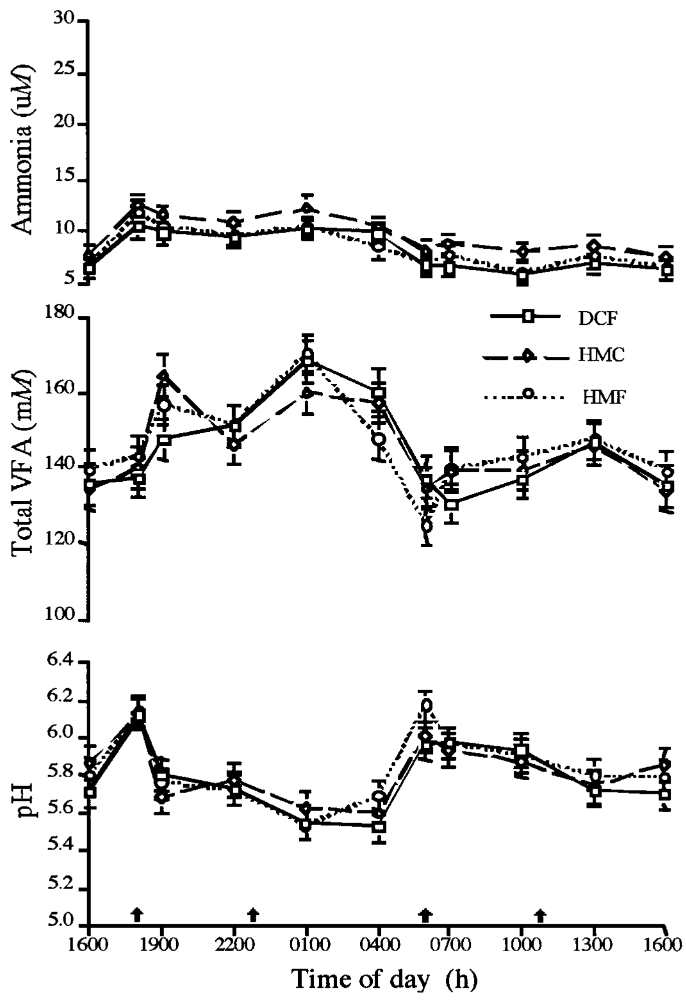

Figure 2. Daily pattern of ruminal ammonia, total VFA, and pH of cows ad libitum direct-cut grass-legume forage and 10 kg/d of concentrate based on either finely ground dry shelled corn (DCF), coarsely ground high moisture corn (HMC) or finely ground high moisture corn (HMF) in Experiment 2. Vertical bars are SE of treatment mean. Forage and concentrate feeding times are indicated by ⬆.

Table 7. Ruminal digesta kinetics of cows fed various concentrate and direct-cut grass-legume forage.

	Treatments[1]					Contrasts, *P*	
	DCF	HMC	FFO	SEM	Trt *P*	DCF and HMC vs. FFO	DCF vs. HMC
Experiment 1							
Rate of passage[2] (k), h^{-1}							
Liquids	0.095	0.097	0.116	0.009	0.29	0.13	0.85
Forage	0.034	0.036	0.038	0.003	0.46	0.33	0.45
Grains	0.073	0.072	. . .	0.055	0.91		0.90
	DCF	HMC	HMF	SEM	Trt *P*	DSC vs. HME[3]	HMC vs. HMF
Experiment 2							
Rate of passage[2] (k), h^{-1}							
Liquids	0.110	0.100	0.100	0.008	0.53	0.48	0.39
Forage	0.023	0.024	0.025	0.003	0.40	0.27	0.43
Grains	0.073	0.067	0.061	0.005	0.10	0.08	0.16

[1]FFO = Direct-cut grass-legume forage (FF) with no supplementation; DCF = FF plus 10 kg DM of concentrate based on ground, dry shelled corn; HMC = FF plus 10 kg DM of concentrate based on high moisture ear corn-coarsely ground; HMF = FF plus 10 kg DM of concentrate based on high moisture ear corn-finely ground.

[2]Fractional rate of passage per h.

[3]High moisture ear corn (HMC and HMF).

(Table 8). The dry corn concentrate had smaller fractions of soluble DM (fraction A) and indigestible DM (fraction C), a larger fraction of slowly degraded DM (fraction B), and a slower rate of ruminal DM degradation than did the high moisture corn supplement.

Fresh forages typically contain high proportions of soluble (fraction A) and slowly digested (fraction B) DM compared with wilted silages or hay (Depies, 1994). The ruminal degradation rates of forage DM in the present study (0.11, 0.08, and 0.10 per hour for

Table 8. In situ DM degradation of direct-cut forage, ground, dry shelled corn, and high moisture ear corn based concentrates in cows fed various concentrates and direct-cut grass-legume forage (experiment 1).

	Treatments[1]					Contrasts, *P*	
	DCF	HMC	FFO	SEM	Trt *P*	DCF and HMC vs. FFO	DCF vs. HMC
Forage DM, kinetic parameters[2]							
Fraction A	0.326	0.315	0.320	0.004	0.28	0.93	0.15
Fraction B	0.471	0.458	0.470	0.003	0.15	0.28	0.10
Fraction C	0.203[c]	0.227[a]	0.209[b]	0.001	0.01	0.02	0.01
k, h^{-1}	0.083[c]	0.108[b]	0.111[a]	0.001	0.01	0.01	0.01
Lag, h	0.05	0.10	0.13	0.03	0.23	0.18	0.25
RDDM[3], %	65.4	64.8	66.4	0.7	0.46	0.29	0.61
Dry corn concentrate DM, kinetic parameters[2]							
Fraction A	0.248	0.328	0.333	0.019	0.76	0.84	0.51
Fraction B	0.618	0.650	0.642	0.020	0.59	0.76	0.34
Fraction C	0.034[a]	0.022[b]	0.025[b]	0.002	0.04	0.26	0.02
k, h^{-1}	0.07	0.06	0.06	0.01	0.83	0.87	0.59
High moisture corn concentrate DM, kinetic parameters[2]							
Fraction A	0.425	0.481	0.445	0.025	0.40	0.80	0.21
Fraction B	0.459	0.445	0.438	0.033	0.90	0.75	0.78
Fraction C	0.116	0.074	0.117	0.021	0.37	0.44	0.25
k, h^{-1}	0.13	0.07	0.17	0.04	0.34	0.26	0.36

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

[1]FFO = Direct-cut grass-legume forage (FF) with no supplementation; DCF = FF plus 10 kg DM of concentrate based on ground, dry shelled corn; HMC = FF plus 10 kg DM of concentrate based on high moisture ear corn-coarsely ground; HMF = FF plus 10 kg DM of concentrate based on high moisture ear corn-finely ground.

[2]A: instantaneously degraded fraction; B: slowly degraded fraction; C: undegradable fraction; k, rate of degradation of fraction B.

[3]Ruminally degraded DM.

FF0, DCF, and HMC, respectively) are similar to values reported by Depies (1994). Supplemental grain decreased ($P < 0.01$) forage DM degradation rates in experiment 1. The rates of forage DM degradation were slower when cows were fed the DCF supplement than when they were fed HMC, which could be due to higher intake of SFG with the DCF treatment. The reduced rate of forage DM degradation did not influence apparent DM, OM, or fiber (NDF and ADF) digestibility for supplemented cows.

Experiment 2. The passage of liquids and forage was not affected by the source of corn or by particle size of the high moisture concentrate. However, cows fed high moisture ear corn supplements tended ($P = 0.08$) to have slower passage rates for the grain portion of the diet than cows fed DCF (Table 7).

CONCLUSIONS

Ground, dry shelled corn and high moisture ear corn-based concentrates improved milk production and tended to improve gross efficiency of SCM and EM of lactating cows fed fresh cut grass-legume forage. Although they had lower SFG intake and higher fecal SFG concentrations than DC, the higher soluble fraction and higher rate of DM degradation of high moisture ear corn actually resulted in more concentrate DM degradation in the rumen, which resulted similar milk and solids corrected milk production between the two supplements. Feeding 10 kg/d of grain supplements decreased ruminal pH, ammonia, acetate to propionate ratio, and increased ruminal propionate concentration relative to diets with no supplemental grain. The reduction in ruminal pH did not affect either DMI or DM digestibility. The reduction in ruminal ammonia concentrations and higher urinary allantoin to creatinine ratio of supplemented cows compared with cows fed only fresh forage suggest that more energy was available for microbial growth when grain supplements were provided. The source of corn in the concentrate did not change the ruminal pH, ammonia, acetate to propionate ratio, or propionate concentration.

Estimates of intake based on indigestible ADF as an internal marker were lower than direct intake measurements. For this reason, estimates of DM digestibility were different between techniques and in this study the effects of grain supplementation on digestibility were overestimated when indigestible ADF was used as the marker.

Neither milk production or milk composition were affected by source of corn or particle size of the high moisture concentrates. However, ruminal ammonia concentrations were reduced when corn was finely ground. Ruminal ammonia utilization was improved by fine grinding the high moisture corn, probably reflecting greater ruminal starch digestibility and more microbial protein synthesis. The differences in corn particle sizes between treatments in this experiment were small. If greater differences in corn particle size had been tested, more pronounced animal responses might have resulted.

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