# Effect of a Prepartum Administration of Monensin in a Controlled-Release Capsule on Apparent Digestibilities and Nitrogen Utilization in Transition Dairy Cows

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## ABSTRACT

The influence of a monensin controlled-release capsule, which was administered 3 wk before the calving date, on diet digestibility and nitrogen utilization was investigated in 16 multiparous dairy cows between approximately 10 and 3 d precalving and 3 and 9 d postcalving. Monensin decreased rumen ammonia from 5.4 to 3.2 mg $dl^{-1}$ precalving and from 6.0 to 4.9 mg $dl^{-1}$ postcalving. Blood urea concentrations were increased by monensin from 4.93 to 5.28 m*M* precalving and from 5.27 to 5.81 m*M* postcalving, but these increases were not statistically significant. Precalving, monensin increased the apparent digestibilities of neutral detergent fiber from 52.8 to 62.1%, of acid detergent fiber from 50.7 to 58.7%, and of gross energy from 60.5 to 66.7%. Postcalving, monensin increased the apparent nitrogen digestibility from 63.7 to 71.5%, which resulted in an improvement in the nitrogen balance from –77.8 to –44.9 g $d^{-1}$. The monensin controlled-release capsule contributed to increasing the availability of dietary nitrogen to the transition dairy cow during the critical postcalving period.

(**Key words:** transition dairy cow, monensin controlled-release capsule, digestibility, nitrogen balance)

**Abbreviation key: BUN** = blood urea nitrogen, **CRC** = controlled-release capsule, **GE** = gross energy.

## INTRODUCTION

During early lactation, high yielding dairy cows cannot consume enough DM to meet nutrient requirements (NRC, 1989). Bell (1995) found that at 4 d postpartum the requirements for $NE_L$ and metabolizable protein exceeded intakes by 26 and 25%, respectively. This necessitates the mobilization of endogenous stores of fat and protein. Motyl and Barej (1986) used 3-methyl histidine as an index of muscle protein breakdown and estimated that the average muscle breakdown was 434 g $d^{-1}$ between d 5 and 10 postpartum. Muscle breakdown was reduced to 391 g $d^{-1}$ between d 65 and 70 postpartum. Similarly, Komaragiri and Erdman (1997) observed that cows mobilized, on average, 21 kg of body protein between 2 wk before calving until 5 wk after calving, whereas Komaragiri et al. (1998) observed that cows mobilized, on average, 12 kg of body protein during this period. Maltz and Silanikove (1996) determined that high yielding dairy cows had a negative nitrogen balance of 52 and 40 g $d^{-1}$ at 2 and 7 wk postpartum, respectively. Komaragiri and Erdman (1997) assumed that cows have a greater capacity to mobilize body fat than protein and that in high yielding dairy cows both energy and protein are limiting. No conclusive data exist on the adverse effects of the negative nitrogen balance on production and health of the transition dairy cow. However, it is believed that a reduction of this negative balance will contribute to increased production and health and the more efficient use of dietary protein in early lactation by dairy cows.

A monensin controlled-release capsule (Rumensin **CRC**) has been approved in Canada as an aid in the prevention of subclinical ketosis in lactating dairy cows. The monensin CRC has a positive effect on energy indicators, as it lowers the concentration of blood BHBA and increases blood glucose in early lactation dairy cows (Duffield et al., 1998a, Green et al., 1999). This reduces the incidence of subclinical ketosis during this critical period (Duffield et al., 1998b). In herds at increased risk of ketosis, monensin increases projected 305-d milk production (Duffield et al., 1999).

Sodium monensin premix reduces microbial degradation of dietary protein and ammonia production in the rumen (Hanson and Klopfenstein, 1979; Poos et al., 1979). This increases the amount of dietary protein reaching the lower gastrointestinal tract, where it can

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be digested and absorbed, thereby sparing dietary AA. This can explain why administration of monensin premix in a range of 27 to 33 mg/kg has increased the apparent digestibility of CP in steers ranging between 2.1 to 7.6 percentage points (Beede et al., 1986; Wedegaertner and Johnson, 1983). However, other studies in steers and dairy cattle did not find that a similar level of monensin premix supplementation caused a significant improvement in the apparent digestibilities of dietary nitrogen (Haïmoud et al., 1995). This discrepancy could partly be due to dietary composition, as the diets used in the latter two studies were comparatively high in forage. This would confirm the theory of Van Soest (1994) that ionophores are more effective in reducing rumen protein degradation in diets containing rapidly degrading concentrate sources than in hay- and silage-based diets because the soluble protein of hays and silages has a high concentration of NPN compared with that of concentrate feeds. Horton et al. (1980) also reported a significant interaction between monensin and the level of barley on digestibility of CP and crude fiber in steers. Monensin only improved digestibility at low levels of barley inclusion, i.e., up to 30%. Wedegaertner and Johnson (1983) and Faulker et al. (1985) reported that, after an adaptation period, monensin increases the apparent digestibility of fiber. Nevertheless, Beede et al. (1986) did not observe such an effect, and Poos et al. (1979) found that high levels of monensin premix (38 mg/kg) reduced fiber digestion.

The effects of monensin on nitrogen utilization and the apparent digestibility of NDF, ADF, and gross energy in high yielding transition dairy cows have not yet been determined. Results obtained with lactating dairy cows beyond the transition period are not sufficiently conclusive to predict these effects. The insufficient nutrient status of early lactation cows justifies research into improving the digestibility of the diet and especially the availability of nitrogen. Hence, the objective of this study was to determine the effect of a sodium monensin CRC on diet digestibility and nitrogen utilization in transition dairy cows.

## MATERIALS AND METHODS

### Experimental Procedures

Sixteen second- and third-lactation Holstein cows were blocked in pairs of two based on their expected caving date. Rumen fistulations were carried out between 2 and 3 mo precalving. Experimental cows within each block were randomly assigned to one of two treatments: a monensin CRC (Rumensin CRC Provel, Division Eli Lilly Canada Inc., Guelph, ON, Canada) or a placebo CRC (Provel, Division Eli Lilly Canada Inc., Guelph, ON, Canada). The monensin CRC contained 32 g of monensin sodium blended into a hexaglycerol distearate matrix core. The monensin CRC delivers (mean ± SD) 335 ± 33 mg of monensin/d for approximately 95 d. The placebo CRC was identical to the monensin CRC but contained no monensin sodium in the core. The CRC was administered approximately 3 wk before the expected calving date.

**Table 1.** Ingredient composition (% as fed) of the diet for lactating cows and close-up dry cows (SE in parentheses).

| Ingredient | Lactating cow diet | Close-up dry cow diet |
|---|---|---|
| Corn silage | 42.6 (2.7) | 44.1 (2.9) |
| High moisture corn | 14.5 (1.4) | 7.5 (0.4) |
| Mixed haylage | 23.3 (1.1) | 32.4 (0.8) |
| Mixed hay | 5.7 (0.7) | 10.5 (0.3) |
| Soybean meal | 6.4 (0.4) | 2.4 (0.03) |
| Lactating cow supplement | 7.5 (0.5) | . . . |
| Dry cow pellets | . . . | 3.1 (0.0) |

Cows entered the experiment between February 1998 and January 1999. Calving dates were distributed evenly throughout the experimental period. Approximately 4 wk before the expected calving date, animals were moved to the physiology wing of the Elora Dairy Research Centre (Ontario, Canada) where they were housed in individual tie stalls. Animals were fed a total mixed diet ad libitum twice daily at 0700 and 1300 h. At calving, animals were switched from a close-up dry cow diet to a lactating cow diet (Tables 1 and 2). For the first 3 wk after calving, cows also received 1.8 kg of alfalfa hay once daily. Cows had unlimited access to fresh water. Animals remained in the physiology wing until 1 to 2 d before calving, and then moved to a maternity pen until 3 d postcalving. Between approximately 10 and 3 d before the expected calving date and 3 and 9 d after the calving date, digestibility and nitrogen balance determinations were conducted. Two cows were excluded from the precalving determinations due to earlier than expected calving dates, resulting in insufficient length of the collection period. One cow was excluded from the postpartum determinations due to a displaced abomasum. Blood samples were obtained with a jugular vein catheter every 3 h for 24 h at approximately 7 d before the expected calving date (precalving) and at 7 d after the calving date (postcalving). Rumen fluid samples were also collected at these times.

### Digestibility and Nitrogen Balance Determinations

These determinations were conducted during two periods with durations of between 5 to 7 d. The first period began approximately 10 d precalving. The second period began approximately 3 d postcalving. The amounts of total mixed diet and alfalfa hay offered each day were

recorded. Representative feed and weigh back (orts) samples were taken each day. Diets and orts were pooled by weight for each cow and period. The DM contents of feeds and orts were determined by drying in a 60°C oven for 48 h (AOAC, 1990). Dried feed samples were ground using a Wiley mill through a 1-mm screen (Thomas Wiley, Philadelphia, PA). All samples were subsequently stored at –20°C until analyzed.

Milk samples were collected from all morning and afternoon milkings and preserved with 2-bromo-2nitropropane-1-2-diol. These samples were then pooled daily based on production and frozen at –20°C.

Urine was collected using indwelling bladder catheters (26 Fr., 75 ml; CR Bard Inc. Covington, GA) similar to the method described by Crutchfield (1968). Modification of this technique included leaving the catheter in place, unconnected to collection tubing for 24 h before collection, and using distilled water to inflate the catheter balloon, as described by Wright et al. (1998). Animals were administered 15 ml of Excenel (ceftiofur sodium sterile powder, Upjohn, Kalamazoo, MI) intramuscularly for 3 d following the removal of the catheters. Urine was collected under acid conditions with 175 ml of concentrated sulfuric acid (Fisher Scientific, Fairlawn, NJ) added daily to the empty polyethelene urine collection containers. A 5% subsample of urine was taken each day during the collection period. Daily urine samples were also collected, diluted five times with distilled water, and frozen at –20°C.

All feces were collected in large steel trays positioned over the gutter behind each stall. Every day at approximately 0900 h, all manure was removed from the trays and placed in large plastic tubs. Material was weighed and thoroughly mixed, and subsamples (approximately 1 kg) were taken and frozen at –20°C until further analysis. Before analysis, frozen samples were thawed, mixed, and placed in aluminum trays for freeze drying. At this time, subsamples were also taken (approximately 100 g) for oven DM determination using a 60°C oven for 48 h. Freeze- dried samples were ground through a 1-mm screen (Thomas Wiley), and pooled by weight (using oven DM values) for each cow and period.

Pooled samples of feeds, orts, and feces were analyzed for CP using the macro-Kjeldahl procedure (AOAC, 1990), ADF (AOAC, 1990), NDF (Goering and Van Soest, 1970), and gross energy (**GE**). The GE was determined with a C-5000 calorimeter (IKA Analysetechnik, Heitersheim, Germany). Pooled samples of total mixed diet and alfalfa hay were also analyzed for soluble protein (Licitra et al., 1996), RDP (Licitra et al., 1999) and

**Table 2.** Dietary analysis (DM basis) for experimental diets (SE in parentheses).

| Item | Close-up dry cow diet | Lactating cow diet | Dry cow pellet | Lactating cow supplement | Hay |
|---|---|---|---|---|---|
| DM, % | 46.2 (0.7) | 50.4 (0.4) | 86.1 | 92.0 | 86.7 (1.2) |
| CP, N × 6.25, % | 13.7 (0.7) | 15.3 (0.5) | 20.1 | 22.5 | 16.3 (0.6) |
| Soluble protein, % of CP | 35.1 (3.0) | 25.6 (2.7) | 29.0 | 16.8 | 38.6 (1.6) |
| Undegradable Intake Protein, % of CP | 47.1 (2.2) | 46.3 (1.3) | 63.0 | 86.3 | 32.0 (0.7) |
| NDF, % | 39.4 (1.1) | 33.9 (0.8) | 29.9 | 26.3 | 47.5 (0.9) |
| ADF, % | 23.6 (1.0) | 20.4 (0.5) | ND | ND | 35.0 (1.6) |
| ADF-CP, % | 1.1 (0.1) | 1.6 (0.3) | ND | ND | 1.1 (0.1) |
| Total fat, % | ND[1] | ND | 3.0 | 4.6 | ND |
| Nonfiber carbohydrates, % | ND | ND | 32.6 | 21.2 | ND |
| Calcium, % | 1.0 (0.1) | 1.0 (0.05) | 1.5 | 4.3 | 1.0 (0.05) |
| Phosphorus, % | 0.5 (0.03) | 0.5 (0.01) | 0.5 | 1.6 | 0.3 (0.02) |
| Potassium, % | 1.5 (0.07) | 1.6 (0.03) | 1.0 | 1.3 | 2.2 (0.1) |
| Magnesium, % | 0.4 (0.02) | 0.4 (0.01) | 1.0 | 1.5 | 0.2 (0.02) |
| Sodium, % | 0.2 (0.02) | 0.4 (0.04) | 0.6 | 2.5 | 0.05 (0.01) |
| Sulphur, % | ND | ND | 0.8 | 0.9 | ND |
| Chloride, % | ND | ND | 0.6 | 1.9 | ND |
| Iron, mg/kg | ND | ND | 235.7 | 317.9 | ND |
| Zinc, mg/kg | ND | ND | 249.9 | 909.4 | ND |
| Copper, mg/kg | ND | ND | 44.4 | 156.3 | ND |
| Manganese, mg/kg | ND | ND | 138.9 | 413.7 | ND |
| Selenium, mg/kg | ND | ND | 1.3 | 2.4 | ND |
| Cobalt, mg/kg | ND | ND | 0.6 | 2.3 | ND |
| Iodine, mg/kg | ND | ND | 2.1 | 8.8 | ND |
| Vitamin A, KIU $kg^{-1}$ | ND | ND | 21.5 | 91.6 | ND |
| Vitamin D, KIU $kg^{-1}$ | ND | ND | 8.6 | 36.6 | ND |
| Vitamin E, KIU $kg^{-1}$ | ND | ND | 850.2 | 329.4 | ND |
| Calcium:Phosphorus ratio | 2.1 (0.2) | 2.0 (0.1) | ND | ND | 3.5 (0.2) |
| $NE_l$[2], Mcal $kg^{-1}$ | 1.50 | 1.56 | ND | ND | 1.29 |

[1]Not determined.

[2]Estimated using equations and values according to NRC (1989).

Ca, P, K, Mg, and Na by inductively coupled plasma spectroscopy (AOAC, 1990) using a Perkin Elmar Optima 3000 spectrophotometer. Milk and urine samples were analyzed for CP using the macro- Kjeldahl procedure (AOAC, 1990).

### Blood and Rumen Fluid Collection and Analysis

Blood samples were collected with a jugular catheter. Blood for the harvesting of serum was collected in 10-ml red top Vacutainers (Becton Dickinson, Franklin Lakes, NJ) that did not contain anticoagulant. Blood was left to clot at ambient temperature for 1 h, after which Vacutainers were centrifuged at 3000 rpm for 20 min. After harvesting, serum was frozen at –20°C until analysis.

Blood serum was analyzed at the Animal Health Laboratory of the University of Guelph. A blood urea nitrogen (**BUN**) kit (cat no. 1 489 321 Boehringer Mannheim, Mannheim, Germany) was used to determine serum BUN concentration with the BM/Hitachi 911 analyzer (Boehringer Mannheim). Approximately 300 ml of rumen fluid was collected from the ventral sac through the cannula using a probe and a vacuum pump. Rumen fluid samples were frozen (–20°C) until further analysis. The concentration of ammonia nitrogen in the rumen fluid was determined using the indophenol-blue colorimetric method according to Novozamski et al. (1974).

### Purine Derivatives

The diluted (1/5) urine samples were analyzed for allantoin and uric acid. Allantoin was measured according to the colorimetric method proposed by Fujihara et al. (1987). A commercial kit was used to analyze uric acid (Sigma, procedure no. 686; Sigma Chemical Co., St. Louis, MO).

### Statistical Analysis

Analysis of variance was conducted using the SAS General Linear Models procedure (SAS, 1990) using the following general model:

$$Y_{ij} = \pi + \alpha_i + \beta_j + \varepsilon_{ij}$$

Where:

$Y_{ij}$ = observation on the treatment i in block j,
$\pi$ = overall true mean,
$\alpha_i$ = effect of treatment (i = 1,2),
$\beta_j$ = effect of block (j = 1,2,..8), and
$\varepsilon_{ij}$ = random residual error.

If observations were of a repeated nature, i.e., the rumen ammonia and BUN data, then the repeated measurement option within the SAS general linear models procedure (SAS, 1990) was used. Statistical significance was accepted at $P < 0.05$.

## RESULTS

The experiment was conducted with diets already in use at the Elora Dairy Research Centre. The ingredient compositions of the lactating cow diet and the close-up dry cow diet are given in Table 1. The analysis of the experimental diets is given in Table 2. The lactating cow diet was higher in CP and $NE_L$, but lower in NDF, ADF, and soluble protein than the close-up dry diet. The nutrient content of the diets met or exceeded NRC requirements (NRC, 1989). The composition of these diets changed as the experiment was conducted from February 1988 until March 1999. Hence, Tables 1 and 2 provide standard errors to indicate the range in diet composition. These standard errors show that changes in diet composition were not substantial.

Monensin did not affect DMI (Table 3). Apparent digestibilities of DM, GE, N, NDF, and ADF determined precalving and postcalving are given in Tables 3 and 4. Monensin improved apparent DM digestibility numerically both precalving and postcalving, but these improvements were not statistically significant. The NDF and ADF digestibilities were increased by 9.3 and 8.0 percentage points ($P < 0.05$), respectively, by monensin precalving. This resulted in an increase in GE digestibility of 6.2 percentage points ($P < 0.05$). There was also a trend that monensin increased GE digestibility postcalving. Postcalving, monensin did not affect NDF and ADF digestibility. Nitrogen digestibility was not affected by monensin precalving, but in the postcalving period, it increased apparent nitrogen digestibility from 63.7 to 71.5% ($P < 0.05$).

Monensin decreased rumen ammonia from 5.4 to 3.2 mg $dl^{-1}$ precalving and from 6.0 to 4.9 mg $dl^{-1}$ postcalving. These decreases were, however, not statistically significant. The BUN levels were increased by monensin from 4.93 m*M* to 5.28 m*M* precalving and from 5.27 to 5.81 m*M* postcalving. These increases were not statistically significant.

The results related to the nitrogen balance measurement are presented in Table 4. Nitrogen intake, fecal nitrogen output, and nitrogen retention were not affected by monensin precalving. Monensin increased urinary nitrogen output precalving, but this was also not statistically significant. Postcalving, monensin did not affect DMI, nitrogen intake, and milk nitrogen output, but it significantly decreased fecal nitrogen output ($P < 0.05$) and improved nitrogen balance ($P < 0.05$). The

**Table 3.** Intakes, fecal outputs, and apparent digestibilities (ADC) of DM, gross energy, NDF, and ADF (SE in parentheses).

| | Precalving | | Postcalving | |
|---|---|---|---|---|
| Item | Monensin | Control | Monensin | Control |
| DM | | | | |
| Intake, kg $d^{-1}$ | 11.8 (0.70) | 10.6 (1.0) | 15.5 (0.9) | 15.6 (0.8) |
| Fecal output, kg $d^{-1}$ | 4.0 (0.4) | 4.1 (0.5) | 4.7 (0.3) | 5.2 (0.3) |
| ADC, % | 66.5 (2.1) | 61.2 (2.6) | 69.5 (1.3) | 66.7 (1.4) |
| Gross energy | | | | |
| Intake, Mcal $d^{-1}$ | 43775 (3264) | 47187 (4380) | 67204 (3421) | 68487 (2962) |
| Fecal output, Mcal $d^{-1}$ | 14577[a] (1504) | 18939[b] (2017) | 21935 (1482) | 23902 (1283) |
| ADC, % | 66.7[a] (1.8) | 60.5[b] (2.3) | 68.7[y] (1.5) | 65.1[z] (1.4) |
| NDF | | | | |
| Intake, kg $d^{-1}$ | 4.1 (0.3) | 4.41 (0.4) | 5.42 (0.3) | 5.67 (0.2) |
| Fecal output, kg $d^{-1}$ | 1.6[a] (0.2) | 2.08[b] (0.2) | 1.93 (0.2) | 2.16 (0.2) |
| ADC, % | 62.1[a] (2.1) | 52.8[b] (2.6) | 64.4 (1.8) | 61.9 (1.7) |
| ADF | | | | |
| Intake, kg $d^{-1}$ | 2.4 (0.2) | 2.70 (0.2) | 3.22 (0.2) | 3.48 (0.1) |
| Fecal output, kg $d^{-1}$ | 1.00[a] (0.1) | 1.33[b] (0.2) | 1.34 (0.1) | 1.38 (0.1) |
| ADC, % | 58.7[a] (2.1) | 50.7[b] (2.7) | 58.4 (2.1) | 60.3 (1.9) |

[a,b]Means within a row within precalving or postcalving with different superscripts are significantly different ($P < 0.05$).

[y,z]Means within a row within precalving or postcalving with different superscripts are different ($P < 0.10$).

cows in the control group lost on average 77.8 g $d^{-1}$ of nitrogen, which corresponds to a daily loss of 486 g $d^{-1}$ of body protein.

Monensin reduced the urinary excretion of purine derivatives precalving and postcalving (Table 5), but these reductions were not statistically significant. This numerical reduction was greater precalving than postcalving.

Block had a significant effect on NDF digestibility precalving ($P < 0.05$), ADF digestibility precalving ($P < 0.05$), GE digestibility precalving ($P < 0.05$), nitrogen digestibility postcalving ($P < 0.05$), and nitrogen balance postcalving ($P < 0.05$).

## DISCUSSION

The absence of an effect of monensin on DMI contradicts the observations from Sauer et al. (1998) and Wagner et al. (1999) that monensin premix fed at an inclusion rate of 8 to 33 mg/kg reduces DMI in a dose-dependent manner. In our experiment, the ratio between the daily release from the CRC and the DMI was 29.8 mg/kg precalving and 21.5 mg/kg postcalving, which is a medium to high level of monensin administration compared with these earlier studies. The earlier studies focused on cows throughout lactation, rather than on transition dairy cows. In the transition period, physical fill and diet digestibility might be the main factors limiting DMI, rather than metabolic signals (NRC, 1989). Monensin did not decrease, but rather increased, dietary digestibility in our experiment. Hence, it was not expected that monensin would substantially reduce DMI in transition dairy cows. Also, all earlier studies administered monensin as a premix, whereas a CRC was used in our experiment. This difference in administration could also have influenced the effect of monensin on DMI.

**Table 4.** Nitrogen balance measurements (g $d^{-1}$) (SE in parentheses).

| | Precalving | | Postcalving | |
|---|---|---|---|---|
| Item | Monensin | Control | Monensin | Control |
| N Intake | 255.9 (25.1) | 225.7 (29.7) | 395.6 (23.0) | 374.7 (21.6) |
| Fecal N output | 81.5 (8.6) | 81.2 (10.1) | 109.6[a] (8.2) | 136.9[b] (7.7) |
| Urine N output | 145.0 (20.6) | 115.8 (24.4) | 164.6 (9.8) | 154.4 (9.2) |
| Milk N output | . . . | . . . | 166.3 (9.6) | 161.2 (9.0) |
| N retention | 29.5 (7.4) | 28.6 (8.7) | –44.9[a] (11.3) | –77.8[b] (10.5) |
| N ADC[1] | 68.2 (2.27) | 63.8 (2.87) | 71.5[a] (1.44) | 63.7[b] (1.39) |

[a,b]Means within a row within precalving or postcalving with different superscripts are significantly different ($P < 0.05$).

[1]Apparent digestibility coefficient.

**Table 5.** Urinary excretion of purine derivatives (SE in parentheses).

| | Precalving | | Postcalving | |
|---|---|---|---|---|
| Item | Monensin | Control | Monensin | Control |
| Allantoin, mmol $d^{-1}$ | 129.9 (13.1) | 160.4 (19.4) | 181.2 (12.6) | 194.1 (11.2) |
| Uric acid, mmol $d^{-1}$ | 19.4 (2.1) | 24.8 (3.1) | 31.4 (3.5) | 34.3 (3.1) |
| Purine derivatives, mmol $d^{-1}$ | 149.3 (14.9) | 185.2 (22.0) | 212.7 (13.8) | 228.4 (12.2) |
| Allantoin/purine derivatives, % | 86.7 (0.9) | 85.5 (1.3) | 85.4 (1.4) | 84.5 (1.2) |

The reductions in the rumen ammonia levels and urinary excretion of purine derivatives, which can be used as an indication for microbial protein synthesis in the rumen (Topps and Elliot, 1965), suggest that monensin increased the proportion of dietary protein that escaped fermentation in the rumen, thereby changing the site of digestion from the rumen to the intestine. This is in agreement with previous studies (Hanson and Klopfenstein, 1979; Poos et al, 1979; Spears, 1990). In our study, we observed numerical differences, but no significant differences, in rumen ammonia levels and urinary excretion of purine derivatives between groups. This could be due to the relatively small sample size and the high variation between cows.

Our findings do not agree with the only other report in the literature on the effect of monensin on dietary digestibility in lactating cattle (Haïmoud et al., 1995). These authors concluded that, due to compensatory digestion in the small intestine, a reduction in the ruminal breakdown of dietary protein and fiber did not affect apparent digestibility of protein and fiber. One difference between our experiment and that of Hamoud et al. (1995) was the stage of lactation. We used early lactation cows, whereas Haïmoud et al. (1995) examined cows beyond 45 DIM with subsequently higher feed intakes. The DMI averaged 17.9 kg $d^{-1}$ in Haïmoud et al. (1995) compared with 11.2 kg $d^{-1}$ precalving and 15.6 kg $d^{-1}$ postcalving in our study. The dose of monensin used was differed, Haïmoud et al. (1995) used 33 mg/kg, whereas in our experiment the ratio between the daily release from the CRC and the DMI was 29.8 mg/kg precalving and 21.5 mg/kg postcalving. Additionally, the experiment of Haïmoud et al. (1995) used one $3 \times 3$ Latin square, hence the number of experimental units was small. We conclude that the findings of Haïmoud et al. (1995) cannot be fairly compared to our study with cows in the transition period.

The increase in apparent digestibility of nitrogen in our study was higher than reported in previous studies with dairy cows, steers, and goats (Beede et al., 1986; Spears, 1990; Wedegaertner and Johnson, 1983). It is believed that the main reason for improved apparent nitrogen digestibility is that a greater proportion of the dietary protein bypasses rumen fermentation in the cows receiving monensin and that the availability of dietary protein in the small intestine is higher than that of microbial protein (Spears, 1990). In transition dairy cows, DMI is lower than in cows later in lactation. Tyrell and Moe (1975) concluded that low intake, which might also result in higher retention time, increases the digestibility of all fractions of the diet, but especially fiber. A higher feed retention time in the rumen would make the effect of monensin on fermentation more pronounced. This could be one of the reasons why monensin increased apparent digestibility more in our study compared with the previous studies.

Monensin did not affect nitrogen digestibility precalving. This can be explained by the differences between the precalving diet and the postcalving diet, and especially the higher concentrate content of the postcalving diet and the higher hay and silage content of the precalving diet (Tables 1 and 2). The literature also suggests an interaction between the effects of diet and monensin on nitrogen digestibility (Beede et al., 1986; Haïmoud et al., 1995; Wedegaertner and Johnson, 1983). Van Soest (1994) assumed that ionophores have a larger effect on the reduction of rumen degradation of dietary protein in concentrate based diets than in diets based on hays and silages, due to the high NPN content of the soluble protein in the latter diets. Hence, it could be expected that monensin would have a larger effect on the sparing of dietary protein in the rumen, and subsequently on the apparent nitrogen digestibility, with the postcalving diet than with the precalving diet.

Care should be taken when extrapolating our results obtained in the transition period to periods later in lactation. Later in lactation the DMI, nitrogen intake, and milk yield will be higher, but feed retention time in the rumen will be lower. Milk yield will also be higher, but the protein content of the milk will most likely be lower. The nitrogen balance will also be higher as indicated by previous work (Komrargiri et al., 1998; Komragiri and Erdman, 1997; Maltz and Silanikove, 1996; Motyl and Barej, 1986).

Monensin increased the apparent digestibility of NDF and ADF precalving, but not postcalving. Low rumen pH can affect fiber digestibility (Calsamiglia et

al., 1999; Slyter, 1976). Continuous rumen pH measurement of the cows involved with our experiment indicated that monensin reduced the average time below pH 6 from 137 to 14.8 $d^{-1}$ during the week before calving (Martin, J. A. Plazier, T. F. Duffield, R. Bagg, P. Dick, and B. W. McBride, unpublished data). Green et al. (1999) also found that monensin increased rumen pH in dairy cows. Hence, monensin could have affected fiber digestibility through its effect on rumen pH. The monensin CRC was administered 3 wk before the expected calving date. Hence, the rumen bacteria will have had time adapting to monensin before the precalving digestibility study. This adaptation may have prevented a reduction in fiber digestibility (Faulkner et al., 1985). Monensin increased GE digestibility precalving through its affect on fiber digestibility.

Block had a significant effect on many digestibility measures. This was expected, as the experiment ran for more than 1 yr. This long duration resulted in small differences in diet composition and differences in ambient temperature and humidity between blocks.

The negative nitrogen balance observed postcalving confirms the findings of Motyl and Barej (1986), Maltz and Silanikove (1996), Komaragiri and Erdman (1997), and Komaragiri et al. (1998) who concluded that early lactation high yielding cows mobilize a substantial quantity of tissue protein to meet nutrient requirements. Monensin increases energetic efficiency of fermentation (Armentano and Young, 1983), which results in a reduction of BHBA, an increase in glucose concentration in the serum and a reduction in the loss of body condition score in early lactation cows (Duffield et al., 1998a). Hence, monensin could have reduced the requirement to use tissue protein as an energy source. The increase in the postcalving nitrogen balance due to monensin appears to be due to an increased apparent digestibility, and not due to changes in the nitrogen excretion in the urine. During the postcalving period, uterine involution will have occurred, and this will have affected the nitrogen balance. Kaidi et al. (1995) determined in cattle that the dry weight of the uterus increases on average from 250 to 2600 g during pregnancy. In normal cows it takes an average of 45 d for uterine involution to be completed (Jainudeen and Hafez, 1993). Thus, in this 45-d period 2350 g of uterine tissues, consisting predominantly of protein, will have to be catabolized. Immediately after calving the daily reduction in uterine tissue mass will be greater towards the end of the uterine involution. It is not assumed that monensin affected uterine involution. Hence, differences in postcalving nitrogen balance between control cows and cows receiving the monensin CRC appear to be a function of improved nitrogen digestibility.

Increases in BUN due to monensin in dairy cows have been reported previously (Duffield et al., 1998a ; Hayes et al., 1996). These studies had much larger sample sizes, which could explain why they obtained significant increases, whereas only numeric increases were observed in our study. Duffield et al. (1998a) suggests that this increase is due to a greater supply of bypass protein to the small intestine and a subsequent increase in the use of absorbed nonessential AA for gluconeogenesis. This would lead to a rise in deamination of these AA and higher concentration of BUN. The significant increase in apparent digestibility postcalving and the numeric increase in this digestibility precalving found in our study supports this theory.

Milk nitrogen output was not affected by monensin during the duration of the experiment. Hence, the postpartum increase in apparent nitrogen digestibility due to monensin, which should have been associated with an increase in the absorption of AA, did not increase milk protein yield, suggesting use of AA for oxidation and protein synthesis in other tissues or both.

## CONCLUSIONS

Under the conditions of this experiment, prepartum administration of a monensin CRC improved apparent fiber digestibility immediately before calving and improved apparent CP digestibility and nitrogen balance immediately after calving. The improved nitrogen digestibility was due mainly to a protein sparing affect of monensin in the rumen. The improved fiber digestibility precalving could be related to improved rumen pH. Monensin did not affect DMI, nitrogen output in the milk, and urinary nitrogen excretion.

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