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Monensin controlled release capsules for improved production and mitigating methane in dairy cows fed pasture

G.C. WAGHORN, H. CLARK[1], V. TAUFA and A. CAVANAGH[1]

Dexcel Ltd, Hamilton, New Zealand

ABSTRACT

Mitigation of ruminant methane is an important component of New Zealand's strategy to lower greenhouse gas emissions. Methods for mitigation must be profitable, easily achievable for producers and be applicable to a wide range of farming systems and topography. The rumen ionophore monensin, is potentially capable of meeting these requirements, but its effects on both production and methanogenesis have been variable with forage diets. A trial was undertaken with 60 lactating Friesian/Holstein dairy cows in early – mid lactation and fed pasture over a 3 month period, to measure effects of a commercially available monensin controlled release capsule (CRC) on milk production, rumen metabolites and methane production. Monensin had no effect on fat or protein yield and therefore milksolids yield, 1.68 kg/day for both groups of cows, was unaffected. Rumen volatile fatty acid ratios, measured in 10 animals, were not affected by monensin treatment and average methane production (323 g/day) was similar for both groups (P=0.961). The absence of benefits from monensin for either production or methane mitigation in dairy cows fed forages as a sole diet are in line with other published data. Monensin CRCs will not provide a profitable route for methane mitigation in ruminants grazed on pasture.

Keywords: monensin, dairy cows; milk production; methane mitigation.

INTRODUCTION

Mitigating methane emissions from ruminant animals must be both profitable and easily achieved to ensure a high level of application by farmers. Profitability will be achieved by increased production or efficiency of feed conversion into products, rather than by lowering costs, and an ideal scenario would result in a diversion of feed energy away from methane into maintenance or production. The losses of feed energy to methane are typically around 10% of dietary metabolisable energy (ME) in forage fed ruminants (Waghorn & Woodward, 2006).

Challenges for researchers, government agencies and farmers include the need for widespread uptake of mitigation strategies. The hilly topography of New Zealand farmland precludes extensive pasture improvement by cultivation and in addition a high proportion of livestock are handled infrequently. Current suggestions for mitigation are limited to selection of individuals with below average methane production (Clark *et al*., 2005), immunisation against methanogens (Wright *et al*., 2004) or use of slow release intra-ruminal devices to alter rumen fermentation. Of the latter, the rumen ionophore, monensin sodium, marketed as the Rumensin® controlled release capsule (CRC) by Elanco, is the only option currently available that is potentially able to meet requirements for profitable, straightforward and widespread application.

The CRC dispenses monensin over a period of 100 days. Most use of monensin has been in cattle fed grain-based total mixed rations (TMR), where it increases the efficiency of feed utilisation by about 6% (Goodrich *et al*., 1984) and can lower methane production by up to 25% (Guan *et al*., 2006). However, the persistence and overall efficacy of monensin for methane mitigation has been variable (Johnson *et al*., 1994; Guan *et al*., 2006).

Benefits of monensin for production and methane mitigation in ruminants fed forages have been variable, with methane emissions reduced in about half of the trials with dairy cows (Van Vugt *et al.,* 2005). Trials have often been of short duration and there is some evidence of adaptation to monensin, (Johnson *et al*., 1994) so the benefits could be short lasting. If the benefits disappear because of adaptation, monensin will not be used by farmers.

The inconsistent effects of monensin given to cows fed forages (Van Vugt *et al.,* 2005) is probably a consequence of the high structural fibre:soluble carbohydrate ratio in grasses. Monensin inhibits Gram negative bacteria, which include fibre degraders, to provide a competitive advantage to Gram positive species, including those which produce propionate. However Gram positive bacteria can only respond if suitable substrates are available, and this is unlikely with fibrous forages. With appropriate diets an alteration of the microflora and products of

[1]AgResearch Grasslands, Palmerston North.

digestion can improve nutrient capture and efficiency of feed utilisation (Waghorn *et al.,* 2007).

The efficacy of monensin for improving production and for methane mitigation in ruminants fed forages requires clarification. The objective of this experiment was to evaluate the Rumensin® CRC in dairy cows by measuring performance and methane production over 75 days. Effects of treatments on milk production, feed intake, rumen function and cow health are presented.

MATERIAL AND METHODS

The 90 day trial was undertaken at Dexcel, Hamilton, in 2005, using 60 lactating cows, commencing at week 7 of lactation. At the beginning of the trial they were divided into two groups of 30 Control and 30 Monensin cows, and within each group, 16 were given an intra-ruminal sulphur hexafluoride (SF_6) capsule to allow methane measurement (*e.g.* Clark *et al.,* 2005). The design comprised a 2 week covariate (uniformity) measurement period, after which monensin CRCs were given (by mouth) to 30 cows. A further 11 weeks of pasture and production measurements were undertaken after CRC administration, and after the completion of the trial, milk production was measured for a further 3 weeks.

All 60 cows were grazed as a single herd under normal farm practice, except during four indoor feeding periods where 32 cows were housed in a Calan gate feeding system to measure feed intakes and methane production. Each indoor feeding period lasted for about 9 days and involved the same 32 cows. The first indoor feeding period was prior to the monensin CRC and then 5, 40 and 70 days after administration of the CRC. Half of the indoor cows and the 14 'outdoor' cows (N=30) had monensin CRCs.

Principal parameters measured over the trial were daily milk yields, liveweight (LW) and pasture composition. During indoor feeding, additional measurements included dry matter intake (DMI), composition of the diet eaten and methane production.

Ten cows with rumen fistulae were included in the indoor feeding groups (5 Controls and 5 with monensin) and these were used to sample rumen contents to measure pH, ammonia and volatile fatty acids (VFA). Rumen fistulae also enabled the retrieval of CRCs from 5 cows to measure rate of monensin release. The SF_6 capsules were retrieved from all 10 fistulated cows to monitor SF_6 release rates.

Cows and pastures

The cows were predominantly Friesian (F) with some Friesian x Jersey (FxJ) crossbred animals. They were selected and balanced across treatments based on days in milk, milksolids (MS) production in the previous season and age. Mean calving date was 6th July, 2005.

Pastures fed outdoors allowed about 40 kg dry matter (DM) per cow per day and although pasture fed indoors was grown under similar conditions, requirements for harvesting resulted in a longer sward than that which was grazed. Cows were given new pasture breaks after morning and afternoon milking, and indoor feeding required pasture to be cut at about 08:00 hrs and 15:00 hrs daily.

Measurements

Routine measurements from all 60 cows included daily milk production (am and pm) and weekly measurement of milk fat, protein and somatic cell counts (SCC). The liveweight of all cows was determined weekly.

Pasture mass was estimated using a visual appraisal based on plate meter calibration before grazing and 20 pasture plucks were taken weekly from all paddocks to be grazed over the next 7 days. Pasture plucks were analysed to indicate the composition of pasture offered.

The cows fed indoors had been trained previously to feed from the Calan gate system, which enabled individuals to access their own feed. They were fed twice daily at about 09:30 hrs and 16:30 hrs, with feed offered and refusals weighed and DM content determined. Samples of feed offered and refused were taken for analysis of composition by near infra-red reflectance spectroscopy (NRS; FeedTECH). Feed DM content was determined in triplicate.

Cows were fitted with harnesses and halters as described by Van Vugt *et al*. (2005) and methane production calculated from concentrations of methane and SF_6 in samples collected over 4 x 24h periods. The methane collection apparatus did not affect cows' access to their feed.

Rumen sampling

The 10 fistulated cows (5 with monensin) were sampled twice daily (after milking; 0800h and 1530h) on two days during each indoor feeding period. Samples of rumen liquor were centrifuged and frozen to determine concentrations of ammonia and VFAs using methods described by Burke *et al*. (2000) and the pH of rumen contents were measured at each sampling.

At the conclusion of the trial, the Rumensin CRCs were retrieved from the 5 fistulated cows and the release of monensin calculated. They were returned to the animals and a further measurement was made 166 days after the initial placement in the rumen.

Statistical analysis

Data were analysed using restricted maximum likelihood (REML) within Genstat (version 8.2) for all 60 cows when grazing and on the 32 cows involved in indoor feeding. Measurements taken prior to administration of the monensin CRC were used as a covariate in both instances. The model for all 60 cows comprised treatments (Control *vs.* Monensin), weeks of measurement (N=14), indoors *vs*. outdoors and interactions. Effects were determined for milk, MS, fat and protein yields, fat and protein percentages, protein:fat ratio, SCC and liveweight. The model for the 32 cows held indoors comprised periods (N=3), treatments and the interactions. Analyses were for DMI, MS and methane emission. A similar model was used to evaluate rumen pH and ammonia, but VFAs were bulked within cows for each period.

RESULTS

Milk production for 14 weeks post-CRC administration averaged more than 21 kg/day and was not affected by monensin (P=0.10; Table 1).

Monensin was associated with a slightly lower milk fat percentage (P=0.05), but this did not affect either MS yield (1.68 kg/day) or protein:fat ratio (0.78, P=0.40; Table 1). There were no treatment effects on milk SCC or liveweight gain, the latter averaging only 0.8 kg/week over the trial.

Pastures

The level of milk production was indicative of good quality and quantity of feed available over the experiment, and only in the final period was there a decline in soluble sugar content of the plucked pasture samples, with a commensurate increase in fibre (Table 2). The DM of pasture plucks taken over 13 weeks averaged 17.3 ± SD 1.7% and mean crude protein (CP) concentration was 23.2 ± SD 1.51%, with 46.7 ± 4.22% for neutral detergent fibre (NDF). The average pre-grazing DM was 3580 kg/ha.

Indoor feeding

Forage cut for indoor feeding was of a lower quality (Table 2), with a lower CP, soluble sugars and a higher NDF concentration in the DM. The differences may have been a consequence of either a lower cutting height or more mature forage used for indoor feeding (to achieve sufficient mass for harvesting) or because pasture plucks were of immature growth that may not have been representative of pasture eaten by the grazing cows.

Table 1: Milk production, somatic cell count and liveweight of 30 Monensin and 30 Control cows averaged over 14 weeks (11 during and 3 weeks immediately after the trial).

	Control	Monensin	P
Milk (kg/day)	21.37	22.00	0.096
Milksolids (kg/day)	1.68	1.69	0.594
Protein (kg/day)	0.724	0.744	0.122
Fat (kg/day)	0.954	0.951	0.874
Fat (%)	4.53	4.37	0.050
Protein (%)	3.39	3.42	0.058
Ratio (Protein:Fat)	0.77	0.78	0.400
Somatic cell count (x 1000/mL)	46.8	54.1	0.763
Liveweight (kg): start of trial	492	493	0.830
Liveweight (kg): after 13 weeks	501	505	0.570

Table 2: Chemical composition of feed offered to cows fed indoors and grazing (pluck samples) during the four indoor measurement periods[a]. All data are g/100 g dry matter (DM) unless indicated.

	Indoors				Grazing			
Period	1	2	3	4	1	2	3	4
Crude protein	19.4	18.3	15.1	19.2	19.2	22.5	23.4	22.5
Fibre (NDF[b])	50.4	50.1	47.1	56.9	40.5	51.7	41.3	54.6
Soluble carbohydrates	16.9	18.2	19.4	12.6	22.7	22.1	19.4	12.5
Ash	10.2	9.9	8.0	9.8	8.6	9.7	9.5	9.6
ME[c] (MJ/kg DM)	11.8	12.1	11.6	11.4	12.5	12.4	12.5	11.8

[a]Period 1: 26-30 September; Period 2: 10-14 October; Period 3: 14-18 November; Period 4: 12-16 December.
Abbreviations: [b]neutral detergent fibre; ME, [c]metabolisable energy.

Despite the differences in forage quality for indoor and outdoor situations, the average milk and MS production was similar for the two environments. Covariate analysis showed there were no differences between Control and Monensin cows fed indoors for milk yield (21.2 and 21.4, respectively; P=0.67) or MS yield (1.65 and 1.63 kg respectively; P=0.72). Milksolids yield declined from about 1.78 kg at the commencement of the Monensin treatment (period 2) to 1.52 kg/day in period 4 (P<0.01).

Dry matter intakes of cows housed indoors increased from 15.0 kg/day during the uniformity period (1) to 17.4 kg/day in period 4 (P<0.01) (Table 3). At the conclusion of the trial (period 4), intakes expressed in terms of metabolic liveweight were 161 and 157 g/kg$^{0.75}$ for Control and Monensin cows respectively (P>0.05).

There were no effects (P>0.05) of monensin on rumen pH, ammonia or concentrations and proportions of VFA (Table 4), however, the impact of pasture with a low CP concentration on ammonia concentrations in period 3 is apparent (P<0.01). Over the trial the ratio of acetate:propionate increased from 3.1 to 4.5, commensurate with the decline in pasture quality (Table 2). There were no treatment differences (P>0.05) in proportions of acetate and propionate, suggesting the monensin CRCs did not alter the rumen microflora.

Methane

Covariate analyses showed methane production during periods 2, 3 and 4 averaged 322.5 g/day for Control cows and 323.0 g/day for Monensin cows (Table 3). Treatments did not affect absolute emissions or emissions expressed in terms of DMI or milk production. Mean values for methane production in terms of feed intake (g CH_4/kg DMI) were not significantly different for period 2 (18.7), period 3 (21.1) or period 4 (19.4; P=0.60; Table 3).

Rumensin CRC

This trial was designed to evaluate existing technology for methane mitigation and production in dairy cows, so measurement of monensin release was not an objective of this study. At the conclusion of the trial, the CRCs were retrieved after 79 days in the rumen and 53-68% of the payload still remained, instead of an anticipated 21% of the payload. This suggests the release rate was about 52% of the anticipated 320 mg/day. Further measurements after 166 days showed 0-27% of the payload still remained.

Table 3: Indoor trial: Daily methane emissions, milk production and feed intakes from 16 Control (Con) and 16 Monensin (Mon) cows during the four measurement periods[a].

	Period							
	1[b]		2		3		4	
	Con	Mon	Con	Mon	Con	Mon	Con	Mon
Methane (g/d)	275	269	277	293	355	330	352	317
Milk (kg/d)	26.3	23.4	24.8	22.5	21.8	20.2	20.0	18.7
MS[c] (kg/d)	2.01	1.83	1.85	1.68	1.67	1.55	1.56	1.48
DMI[d] (kg/d)	15.7	14.2	16.1	14.6	17.1	15.6	18.0	16.9
Liveweight (kg)	524	491	524	494	537	511	538	514

[a]Period 1: 26-30 September; Period 2: 10-14 October; Period 3: 14-18 November; Period 4: 12-16 December.
[b]Uniformity (pre-Monensin) period.
Abbreviations: [c]milksolids; [d]dry matter intake.

Table 4: Rumen pH, ammonia and volatile fatty acid (VFA) concentrations in 5 Control (Con) and 5 Monensin (Mon) cows during the four measurement periods[a]. Data are mean values from am and pm sample times on days 2 and 4 of each sampling period, expressed as mmol/L (except pH).

	Period							
	1		2		3		4	
	Con	Mon	Con	Mon	Con	Mon	Con	Mon
pH	6.30	6.06	6.14	6.01	6.10	6.08	6.14	6.19
Ammonia	75	93	56	73	44	50	100	100
VFA (total)	110	115	111	113	131	125	127	123
Molar proportions:								
Acetate	0.65	0.64	0.66	0.64	0.70	0.69	0.70	0.69
Propionate	0.20	0.21	0.19	0.21	0.15	0.16	0.15	0.16

[a]Period 1: 26-30 September; Period 2: 10-14 October; Period 3: 14-18 November; Period 4: 12-16 December.

DISCUSSION

The results presented here have provided a clear demonstration that monensin CRCs did not lower methane and had little effect on production of dairy cows fed pasture. The lower than anticipated monensin release rate may have lessened its efficiency, but even this lower release (about 170 mg/day) is considered an effective dose.

Monensin and production

The absence of a production or methane response to monensin was not entirely unexpected, as small or nil responses have been reported from dairy cows fed pasture on many occasions. Although a pilot study in the Waikato with cows in late lactation showed a 10% increase in milk protein production in response to monensin CRCs, subsequent trials with cows fed pasture (5 in Australia) summarised by (Lowe *et al.,* 1991) demonstrated only small increases in milk protein (from 0.55 to 0.58 kg/day), with no effect on fat yield. The increased protein production in response to monensin was not observed in a subsequent study of 1000 cows on 6 Australian farms (Lean *et al.,* 1994) or another with about 1100 cows in 12 Australian herds (Beckett *et al.,* 1998). In the latter trial, milk volume was increased by monensin CRCs ($P<0.001$) but fat and protein yields were not changed ($P>0.20$) and there were no benefits of monensin for reproduction or cow health.

Hayes *et al.* (1996) fed pasture as a sole diet to cows in the Manawatu and monensin only improved production in one (November) of 4 measurements over a lactation. Monensin CRC treatment in recent trials has not demonstrated a benefit in production from cows fed pasture in late lactation (Van Vugt *et al.,* 2005), pasture supplemented with white clover (Lee *et al.,* 2004) or pasture fed with maize silage (Waugh *et al.,* 2005).

In a summary of trial results (www.Elanco.co.nz/techtalks), it was concluded that monensin will increase daily MS by 40 g. Responses from the 9 cited New Zealand trials averaged 23 g MS/day, compared to 52 g MS/day from the 8 cited Australian trials. Results from the trial reported here did not demonstrate an increase in MS production, and although daily milk protein averaged 0.724 kg in Controls and 0.744 kg with the monensin CRC ($P=0.12$), milk fat was unaffected (0.925 kg; $P=0.87$). To summarise, increased production resulting from the monensin CRC from pasture fed cows appears to range from 0-25 g milk protein/day, with no effect on milk fat. Greater responses are likely when grain is included in the diet.

Monensin and methane

The absence of a monensin effect on methane production in the trial reported here corresponds to some previous studies where forages have been fed. In trials summarised by Van Vugt *et al.*, (2005), monensin CRC lowered methane production from cows fed an increasing proportion of maize silage with pasture, but in a later trial with the same cows, monensin had no effect on methane production from pasture fed with increasing proportions of white clover. The authors surmised that a high potassium content of the pasture white clover diet may have lessened the effectiveness of monensin (Dawson & Boling, 1987), but the capsules had been in the cows for about 8 weeks by the time effects of white clover were evaluated, so some adaptation may have occurred (*e.g.* Mathison *et al.,* 1998). Adaptation has been demonstrated by Guan *et al*. (2006), who reported 27-30% initial reductions in methane emissions (g/kg DMI) in steers fed TMR, but after 2-4 weeks methane had returned to pre-treatment values.

Smaller reductions in methane production have been reported in response to monensin with steers fed TMR (9% over a 21 day trial; McGinn *et al*., 2004) and cows fed pasture (10%, Van Vugt *et al.,* 2005). In the latter trial the effect appeared to persist over 10 weeks.

Rumen parameters

The absence of methane responses to monensin is not surprising, given the lack of significant treatment effects on rumen parameters (Table 4). Unless there is an alteration in the amount or proportion of propionate and acetate in the rumen, which is characteristic of monensin given to animals fed grain based diets, there will be no change in the quantity of hydrogen available for disposal as methane (Johnson *et al*., 1994; Mathison *et al*., 1998).

Monensin release rate

The monensin CRC release rate measured in 5 of the cows averaged about 170 mg/day, with a mean concentration in the DM eaten (15.7kg/day) of 10.8 mg/kg DM. This value is at the low end of Food and Drug Administration recommended dose rates (11-22 mg/kg feed DM; FDA.gov/CVM/monQA-htm), however responses in milk protein and MS production have been obtained from trials using the Rumensin® CRC devices (*e.g.* www.Elanco.co.nz/Techtalk). Recently, Broderick (2004) demonstrated significant changes in rumen VFAs in cows receiving only 10 mg monensin/kg DM as a TMR, so the low monensin release in the current trial should have been sufficient to affect changes to the rumen microflora. The impact of changes in the microflora will depend on substrates (diet) available, and this and previous studies suggest monensin is not likely to enable consistent or significant production benefits from pasture diets.

CONCLUSIONS

This study and previous evaluations of the monensin CRC have shown zero or small benefits for milk protein production from cows fed pasture alone, so monensin is unlikely to have widespread acceptance in the industry. From a greenhouse gas perspective, the absence of methane mitigation represents a setback in cost effective and acceptable mitigation strategies for ruminant animals.

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