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Feeding maize silage to dairy cows: implications for methane emissions

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ABSTRACT

Maize silage was used on 25% of New Zealand dairy farms in 2003/2004, with 26% of these farms feeding 2 t DM/ha as maize silage. The nutritional value and animal responses to maize silage fed with pasture are well defined, but its impact on rumen methane emissions is not. In an 11-day indoor feeding trial, 32 Friesian dairy cows in mid lactation were fed *ad libitum* pasture with 0, 12, 24 and 36% of the dry matter (DM) intake supplied by maize silage. Pasture and maize silage intakes, milk production and methane emissions were measured. Half of the cows in each treatment group were given intra-ruminal slow release monensin capsules. Total DM intakes were similar for all feed treatments. As maize silage intake increased, milksolids (MS) production decreased linearly from 1.73 (pasture only) to 1.46 kg/day (P = 0.0043, SED = 0.09) and methane emissions increased from 16.3 to 19.0 g/kg DMI (P = 0.0061, SED = 1.03). Increasing proportions of maize silage in a pasture-based diet increased methane emissions from lactating dairy cows. These effects were alleviated by monensin.

Keywords: dairy cows; methane emissions; milk production; perennial ryegrass; maize silage.

INTRODUCTION

Maize silage was used on 25% of New Zealand dairy farms in the 2003/2004 season, with 26% of these farms feeding 2 t DM/ha (Dexcel Profitwatch database for Economic farm survey, 2003/2004). The use of maize silage has been advocated to increase Economic Farm Surplus (Deane, 1999) through extending lactation length, increasing overall stocking rate, or to fill feed deficits in early or late lactation (Deane, 1999; Kolver *et al.,* 2001).

Maize silage provides a low cost source of energy in the form of starch and fibre which complements pasture well for much of the year (Kolver *et al*., 2001). The low crude protein (CP) content of maize silage (7-8%) complements the higher crude protein content of spring or autumn pasture (> 20%). Improving feed quality and altering diet composition offer possibilities for methane mitigation. Factors such as the type of carbohydrate in the diet, level of feed intake, digesta passage rate, presence of ionophores or lipids in the diets and ambient temperature influence the emission of methane from ruminants (McAllister *et al.*, 1996). Whilst the nutritional value and animal responses to maize silage supplemented with pasture are well recognised, there has been little research on its effect on methane output. Woodward (2002) compared methane emissions from cows fed either pasture or pasture (60%) plus maize silage (40%). There was no significant difference in total DM intake, milk solids yield or total methane between the treatments, but methane per unit total DM intake was lower for the maize silage supplemented cows (20.3 g CH_4/kg DM) than those fed pasture only (23.4 g CH_4/kg DM).

Our experiment tested the hypothesis that maize silage and monensin supplementation of dairy cows could reduce methane emission compared with cows fed ryegrass/white clover-based pasture only. This paper will focus on the responses to maize silage feeding whereas van Vugt *et al*. (2005) discuss the response to monensin.

MATERIALS AND METHODS

Trial design

The trial design was a 4 x 2 factorial response curve, using four feeding levels of maize silage with two levels of monensin. Thirty two mixed age (4.7 ± 2.3 years) Friesian dairy cows in mid lactation (115 ± 12 days in milk) were randomised to four dietary treatments in November 2003, balanced for current milksolids yield and live weight. For seven days immediately before the trial, cows were grazed together on ryegrass/white clover–based pastures and their milk yield and composition data collected for use in covariate analysis. The dietary treatments were *ad libitum* cut pasture with 0, 12, 24 and 36% of the dry matter (DM) intake supplied by maize silage. Cows were housed and individually fed in a well-ventilated freestall barn, at Dexcel's Lye farm, Hamilton, Waikato region of New Zealand. The 11-day trial comprised a seven-day adaptation period followed by a four-day measurement period. Four cows in each dietary treatment group were given intra-ruminal slow release capsules, releasing monensin sodium at 320 mg per day (Rumensin® Anti-

Bloat Capsule, Elanco Animal Health, Auckland, New Zealand).

Forage measurements

Pasture and maize silage samples from feed offered and refused were collected daily. A rapid (microwave) DM assessment of the feeds was done at each feeding to determine feed offered. Feed samples for quality and oven DM determination were collected as feed was weighed. Three sub-samples per feed were oven-dried at 95°C (36 h for pasture, 72 h for maize silage) to allow final DMI to be calculated. A further sub-sample of bulked pasture and of maize silage from each feeding was oven dried at 60°C, bulked on a daily basis and ground for analysis of chemical composition by near infrared reflectance spectrophotometry (NIRS systems 6500, Feedtech, AgResearch Grasslands, Palmerston North). Botanical composition of pasture offered was determined from bulked pasture samples by dissection of component species, expressed as % of total DM.

Feeding and intake measurements

Cows were fed their treatment allocation *ad libitum*, aiming for a 10-15% ration refusal, in a Calan™ gate indoor feeding system allowing individual feeding and intake measurement. Cows were adapted to maize silage by progressive additions of maize silage to the basal pasture diet over a six-day adaptation period.

All cows were offered on average 21 kg DM/cow/day. Fresh cut pasture and maize silage were weighed separately on electronic scales and offered to individual cows at about 1000 h and 1700 h daily. Maize silage was thoroughly mixed with pasture by hand at each feeding. Each day, cows were drenched orally with 60 g magnesium chloride and dicalcium phosphate (feed grade), lime flour (Calcimate) and sodium chloride (Summit coarse AgSalt, Summit Animal Health products, Dominion Salt Ltd) were mixed with the feed. Refusals from individual cows were weighed daily and the proportion of maize silage in each refusal visually estimated. Each refusal sample was then blended thoroughly by hand and a subsample taken for DM percent determination.

Milk and live weight measurements

Milk samples (p.m. + a.m.) were collected once during the pre-trial uniformity period and daily during the four-day methane measurement period and analysed for milk fat, milk protein and lactose concentration using a Milkoscan 133B analyser (Foss Electric, Hillerød, Denmark). Daily milk yield was measured via in-line milk meters throughout the trial. Cow live weights were measured before morning milking on one day during the pre-trial uniformity period and on the last two days of the four-day measurement period.

Methane measurements

Methane production was measured using the sulphur hexafluoride (SF_6) tracer technique described by Johnson *et al*. (1994). Brass permeation tubes (35 x 10 mm external diameter) were dosed orally to each cow 47 days prior to the measurement period to release SF_6 marker gas at a known rate (4.0 mg/day) into the rumen. Respired air was sampled continuously above the nose over four, 24-hour periods via a fine bore capillary tube connected to a halter and collected in an evacuated yoke attached over the shoulders of each cow. Background concentrations of atmospheric methane and SF_6 were measured in the indoor facility during the trial. Methane and SF_6 concentrations in the accumulated samples were determined by gas chromatography and the methane emission rate calculated as: $Q_{CH4} = Q_{SF6}$ x ([CH_4 yoke] – [CH_4 background]) / ([SF_6 yoke] – [SF_6 background]), where Q_{SF6} is the calibrated rate of permeation from the SF_6 capsule.

Statistical analysis

GenStat version 7.1 was used to analyse mean milk yield and composition, cow intake and methane data collected over the four-day experimental period by analysis of variance. The analyses tested for maize silage, monensin and their interaction including linear contrasts for levels of maize silage offered. Pre-experimental milk yield and composition data were used as covariates for these variables.

RESULTS

Forage composition

The pasture fed was green and leafy, containing 85% perennial ryegrass, 12% white clover, 0.5% other grasses and 2.5% dead matter. Maize silage and pasture fed were 32.5 and 19.6% DM respectively. Metabolisable energy (ME) contents of maize silage and pasture were 10.6 and 12.1 MJ/kg DM respectively (Table 1). This difference is expected because of the higher levels of acid detergent fibre (ADF) and neutral detergent fibre (NDF) in the maize silage compared with pasture. Pasture organic matter digestibility (OMD) measured by NIRS was 84.7%.

Cow intake

Total DM intakes (kg/cow/day) were similar for all feed treatments. Maize silage intakes were 0, 2.8, 4.8 and 5.9 kg DM with increasing level of maize silage fed. The proportion of maize silage in the diet eaten by the cows was 14.9, 25.5 and 32.0% of total DMI, for the 12, 24 and 36% maize silage feed treatments (Table 2). At the lower levels of maize offered (12 and 24% of total DM) cows appeared to select for maize silage, with the amount of maize silage eaten being slightly higher than that offered. At the highest feeding level, 36%

maize silage offered, cows ate slightly less (32%) maize silage than that offered.

Milk production and live weight

Milk yield decreased from 23.3 to 20.5 kg/day (P = 0.01), as did fat yield (0.95 to 0.80 kg/day, P = 0.015), protein yield (0.79 to 0.66 kg/day, P = 0.0032) and lactose yield (1.17 to 1.00 kg/day, P = 0.015) for non-monensin treated cows as maize silage intake increased. Milk solids (MS) production decreased linearly from 1.73 (pasture only) to 1.46 kg/day as maize silage intake increased (P = 0.0043) (Table 2). Milk fat, protein and lactose concentrations were similar across all feed treatments. Cow live weight (mean = 463 ± 43 kg) and daily gains (2.0 – 2.3 kg/day) were also similar across the treatments. There were significant interactions (P < 0.05) between monensin and maize silage level for milksolids and protein yield and milk protein concentration (Table 2). Briefly there was no effect of maize silage level in the monensin treated cows - refer to van Vugt *et al*. (2005).

TABLE 1: Dry matter (DM) content, chemical composition (g/100g DM) and metabolisable energy (MJ/kg DM) of the maize silage, perennial ryegrass pasture and diets offered to cows. Values are treatment means of daily samples over the four measurement days. Actual maize silage eaten (as % total DM) was 14.9, 25.5 and 32.0 for 12, 24 and 36% levels respectively.

	Maize silage	Pasture	Maize silage (% total DM)		
			12	24	36
Dry matter content (%)	32.5	19.6	21.5	22.8	23.6
Crude protein (CP)	7.6	21.5	19.4	18.0	17.1
Lipid	4.0	3.8	3.8	3.8	3.8
Acid detergent fibre (ADF)	25.7	20.6	21.4	21.9	22.2
Neutral detergent fibre (NDF)	42.7	39.6	40.0	40.4	40.5
Soluble sugars and starch	33.1	14.1	16.9	19.0	20.1
Metabolisable energy	10.6	12.1	11.9	11.7	11.6

TABLE 2: Dry matter (DM) intakes, milk yield and composition for mid-lactation Friesian dairy cows fed an increasing proportion of maize silage with a perennial ryegrass based pasture diet. Values are the mean for each treatment (n = 4 cows) and SED.

	0% maize		12% maize		24% maize		36% maize		
	M+	M-	M+	M-	M+	M-	M+	M-	SED
DM intake (kg DM/cow/day)	18.2	19.2	17.9	19.1	18.6	19.5	18.5	18.3	0.76
Maize silage intake (kg DM/cow/day)	0.0	0.0	2.8	2.8	4.8	4.8	5.4	6.3	0.49
Maize silage eaten (%)	0.0	0.0	15.4	14.4	26.1	24.8	29.0	34.2	2.04
Milk yield (kg/day)	22.7	23.3	22.2	22.3	22.1	22.5	21.6	20.5	0.93
Fat yield (kg/day)	0.85	0.95	0.91	0.94	0.85	0.87	0.87	0.80	0.06
Protein yield (kg/day)	0.72	0.79	0.72	0.73	0.70	0.73	0.73	0.66	0.04
Lactose yield (kg/day)	1.14	1.17	1.10	1.06	1.07	1.10	1.05	1.00	0.06
Milksolids yield (kg/day)	1.58	1.73	1.62	1.68	1.56	1.60	1.60	1.46	0.09
Milk fat concentration (%)	3.81	4.02	4.00	4.43	3.90	3.88	4.14	3.93	0.29
Milk protein concentration (%)	3.16	3.29	3.25	3.38	3.20	3.27	3.38	3.28	0.07
Lactose concentration (%)	4.92	4.87	4.94	4.87	4.90	4.86	4.88	4.92	0.04

TABLE 3: Methane (CH_4) production expressed as absolute values and in terms of dry matter (DM) and gross energy (GE) intakes and milksolids production by cows fed increasing proportions of maize silage with pasture. Values are the mean for each treatment (n = 4 cows) and SED.

	0% maize		12% maize		24% maize		36% maize		
	M+	M-	M+	M-	M+	M-	M+	M-	SED
CH_4/cow/day (g)	306	313	297	314	318	358	313	346	20.2
CH_4/DMI (g/kg)	17.1	16.3	16.4	16.6	17.1	18.3	16.9	19.0	1.03
CH_4/MS (g/kg)	198	188	181	192	202	225	198	235	15.3
CH_4 (% of GE intake)	5.3	5.1	5.1	5.2	5.4	5.7	5.3	5.9	0.32

Methane emissions

Total methane increased by 10% as maize silage increased from 0 to 36% of the diet (P = 0.037; Table 3). Methane emissions per unit DMI increased from 16.3 to 19.0 g/kg DM with increasing maize silage intake (P = 0.0061). Methane emissions per unit MS also increased with increasing maize silage intake, from 188 to 235 g/kg MS (P = 0.0015). Methane energy as a percent of gross energy intake (GEI) also showed this trend. There was a significant interaction (P = 0.036) between monensin and maize silage level for methane per unit milk solids (Table 3). This is discussed further by van Vugt *et al*. (2005).

DISCUSSION

Dry matter intakes of cows were similar across all treatments but the lower ME content of the maize silage, compared with pasture, resulted in a decline in daily ME intake (MJ/cow) from 232 (pasture) to 212 (36% maize silage). This was associated with a decline in daily MS yield and an increase in energy losses to methane from 5.1 to 5.9% of GEI.

DM intake has been identified as the major driver of methane emissions from cattle fed diets containing a range of grass and maize silages (Mills *et al.,* 2003), though the data from this trial and those by Robertson and Waghorn (2002), Woodward *et al.* (2002) and Lee *et al*. (2004) have shown pasture quality had a major effect on the proportion of energy lost to methane. The same cows were fed pasture with differing proportions of white clover (Lee *et al.*, 2004) one month after this experiment, where methane accounted for 6.8% of GEI for the 100% pasture diet, declining to 5.6% of GEI when 60% of the diet was white clover. The pasture had a higher fibre concentration (47.8% of DM) and lower ME compared with pasture fed in this experiment (11.1 vs 12.2 MJ ME/kg DM respectively). In other trials undertaken with Friesian cows at Dexcel, Waghorn *et al*. (2001) reported methane losses increased from 5.3 to 6.6% GEI as ryegrass pasture ME concentrations declined from 12.7 to 11.1 MJ/kg DM in the respective periods. Woodward *et al*. (2002) compared methane production by cows fed pasture alone (NDF 48.1% of DM) or with 40% maize silage (10.4 and 10.5 MJ ME/kg DM) and reported 7.5 and 6.6% of GE lost to methane for the respective diets.

Although the energy losses to methane reported from this trial fall within the range of 5.5 – 7.0% of GE, typical of forage diets (Johnson *et al*., 2000), the impact of a high structural fibre and lower ME content is apparent. The predicted organic matter digestibility of the pasture fed in this experiment was 84.7% and maize silage digestibility was likely to be about 68% (Stockdale, 1995) but the lignified pasture or maize stem will increase rumen retention time and in turn will increase methane production. The data from this and comparable pasture feeding trials including that of Kujawa (1994) who fed highly digestible beet pulp, show rapidly digested diets with short rumen retention times will result in lower methane production as a percentage of GEI.

Increasing proportions of maize silage (without monensin) increased the percentage of ME lost to methane from 7.5 to 9.1% and reduced milk solids production. The partition of ME intakes (212 – 232 MJ/cow/day) to requirements for maintenance (59 MJ/cow/day) and lactation (95 to 112 MJ/cow/day) (Kolver, 2000) suggested 58 to 65 MJ ME/day is available for live-weight gain (Table 4). This corresponds to daily gains of about 2 kg during the experiment.

Although maize silage was highly acceptable, there was a high substitution for pasture and a reduction in ME intake when increasing amounts were offered to cows. Increased intake of maize silage in this experiment reduced cow performance, but the detrimental effects were minimised when monensin was included in the diet.

TABLE 4: Metabolisable energy of mid-lactation Friesian dairy cows fed an increasing proportion of maize silage with a perennial ryegrass-based pasture diet. Values are calculated from means of DMIs, metabolisable energy of the feed and milksolids yield (Tables 1 & 2), using energy values (MJ ME/day) for the lactating dairy cow in Kolver (2000). Assumes maintenance energy for a 450 kg lactating cow is 59 MJ ME/day and energy per kg milk solids for a Friesian cow is 65 MJ ME.

	0% maize	12% maize	24% maize	36% maize
ME intake (MJ/cow/day)	232	227	228	212
ME required for milk production (MJ/cow/day)	112	109	104	95
ME remaining (MJ/cow/day)	61	59	65	58

Practical implications

Maize silage is an important supplementary feed in New Zealand, but feeding of maize silage does not in itself appear to help mitigate methane emissions from dairy cows. Methane emissions per unit intake and unit production increased with increasing proportions of maize silage (up to 36%) in a high quality pasture diet. However, the total level of these methane emissions was low (5.1 to 5.9% of GEI).

When determining practical solutions for methane mitigation all the greenhouse gas (GHG) costs associated with the whole system and the environment need to be considered. Maize cropping produces more GHG emissions per unit feed than permanent pasture because of the carbon dioxide losses associated with soil cultivation and the fuel used in crop husbandry (van der Nagel *et al*., 2003). Maize silage is important in current New Zealand dairy farm systems, for extending lactation length and filling feed deficits, therefore reducing the GHG emissions associated with its production would be very beneficial.

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