Supplementing dairy cows with oils to improve performance and reduce methane – does it work?

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ABSTRACT

Oil supplements can be used in dairy rations to increase dietary energy density (and energy intake) and reduce methane (CH_4) emissions from rumen fermentation. Trials at Dexcel measured effects of oil supplementation on dry matter intake (DMI), milk yield and methane production after lactating dairy cows were fed pasture-based diets for short (14-day) and long (12-week) periods. In the short-term trial, 32 cows received either no oil or three mixtures of sunflower and fish oil at 500g/d. In the long-term trial 20 cows grazed pasture and received either no oil or 300g linseed and fish oil for 11 weeks prior to methane measurements. The type of oil in the short-term trial did not affect methane production and oils had no effect on DMI or milk yield but reduced total methane emissions by 27% (176 vs. 242g CH_4/cow/d, sed=10.6) and CH_4/kg DM (13.5 vs. 18.5g CH_4/kg DM, sed=0.88). In the long-term trial, oil had no effect on methane emissions (353 (oil) vs. 323g CH_4/cow/d (control), sed=17.0 and 21.7 vs. 23.0g CH_4/kg DM, sed=1.01). These trials did not show benefits of oils for milk production and emphasize the need for long-term studies when developing on-farm strategies for methane mitigation.

Keywords: dairy cows; methane emissions; oils; milksolids, pasture; supplements.

INTRODUCTION

Ruminant methane (CH_4) accounts for 34% of New Zealand's greenhouse gas (GHG) emissions and dairy cattle account for about 23% of ruminant methane. Methane is a sink for hydrogen ions derived from enteric fermentation in the rumen and the majority is exhaled through the mouth and nostrils. Methane production by ruminants fed forage diets accounts for 6-7% of gross energy intake (GEI) (Ohara *et al*., 2003), equivalent to about 10% of metabolisable energy (ME) intake. Methanogenesis results in a loss of energy that could be used for milk production.

Methane mitigation options for New Zealand's pasture-based dairy industry must be practical and not compromise productivity. Previous research trials have highlighted a two-fold range in methane emissions per dry matter intake (DMI) when contrasting diets have been fed to sheep, and lowest emissions were reported from the condensed tannin (CT)-containing legume Maku lotus (*Lotus pedunculatus*) (Waghorn *et al*., 2002). The CT in Maku lotus and in birdsfoot trefoil (*Lotus corniculatus*) was responsible for reducing methane emissions (g CH_4/kg DM) by 13-15% in sheep and in dairy cows (Woodward *et al.*, 2004). However forages containing CT and those documented by Waghorn *et al.* (2002) may not always be a viable option on farm, whereas dietary supplements may be more suitable in some situations.

Previous research has shown oils have the potential to reduce enteric methane production. Typically, oils derived from plant or animal sources are able to reduce rumen methane production by up to 25% *in vivo* (Hegarty, 1999; Machmuller *et al.*, 2000). Animal responses to dietary oils vary between trials and an extensive trial with dairy cows failed to demonstrate a reduction in methane emissions (Johnson *et al.*, 2002). Oils can reduce methane simply by acting as a sink for hydrogen derived from rumen fermentation, but this effect is small compared to effects on the microflora themselves (Johnson *et al*., 2002).

Oil supplementation could also have other benefits. Oils are added to total mixed rations to increase the energy density of the diet and increase the nutritional value for animals as well as improve the nutritional characteristics of animal products consumed by humans (Cosgrove *et al.*, 2004). Modifying diet composition can affect the fatty acid profile of milk and milk products to provide added health benefits for consumers eg. increasing the *cis*-9, *trans*-11 isomer of conjugated linoleic acid (CLA) (Chow *et al.*, 2004; Lock & Bauman, 2004).

Effects of oil supplements on methane production and milk production from two trials with lactating dairy cows grazing perennial ryegrass-white clover pastures are presented here. The trials also provided information about the type of oil supplement and the period of supplementation affecting methane mitigation.

MATERIALS AND METHODS

Short-term trial design and management

This 14-day trial was conducted at Dexcel's Lye Farm, Hamilton, in October 2003. Lactating dairy cows were fed perennial ryegrass-based pasture and supplemented with varying proportions of fish oil (FO) and sunflower oil (SFO) during the 10-day preliminary and 4-day measurement periods. The 32 multiparous Holstein-Friesian dairy cows in early lactation (54 ± 15 days in milk) were allocated (8 cows per treatment) to the four treatments on the basis of current milksolids (MS) yield and liveweight. They were given either no oil (control) or 500g/d of oil based on SFO which was substituted with 0, 15, or 30% FO ie. control, 0:500, 75:425, 150:350 g FO:SFO. Throughout the trial, cows receiving oil were drenched twice daily, immediately after morning (0750h) and evening milking (1600h), with equal volumes (250g per drench) of the FO:SFO mixtures. All cows rotationally grazed standard perennial ryegrass-white clover pasture for the first week of the trial at an allowance of 40 kg DM/cow/d. During week two, all cows were housed in a well-ventilated indoor feeding facility and fed cut pasture, using Calan Gates to obtain daily DMI from individual cows. Freshly cut pasture was weighed and fed to cows at 0900h and 1700h daily to ensure daily refusals were 10-15% of offered. Refusals were weighed at 0700h daily. Measurements, including DMI, milk yield and composition (milkfat and milk protein), liveweight and methane production, were made over the final four days, after 10 days of oil supplementation.

Long-term trial design and management

This 12-week trial was conducted at Dexcel's No 5 Dairy, Hamilton in August-October 2004 with cows grazing ryegrass-white clover based pasture. The 20 multiparous Holstein-Friesian dairy cows were balanced across the two treatments (10 cows per treatment) for stage of lactation, milksolids production in the first 12 weeks production in the previous season, age and liveweight. One treatment received no oil supplement (control) while the remaining cows received 300g of oil (200g linseed oil and 100g fish oil) mixed with 1.2kg (DM) of soybean and linseed meal after morning (0750h) milking. During the measurement period in week 12 (after 78 ± 11 days in milk) DMI were estimated using the alkane marker technique (Dove and Mayes, 1991) and other measurements, including milk yield and composition (milkfat and milk protein) and liveweight were taken over four consecutive days in late October in conjunction with methane measurements.

Pasture and milk measurements

In both trials, hand plucks of pasture were taken to represent herbage selected by cows and dried to determine DM (95^{o}C) and chemical composition (65^{o}C) using near infrared reflectance spectrophotometry (NIRS systems 6500). Milk yield (kg/cow/d) was measured daily and milk samples (pm + am) were collected over each measurement period to determine milkfat (%) and milk protein (%) concentration using a Milkoscan 133B analyser (Foss Electric, Denmark). Daily milksolids yield (kg/cow/d) was then calculated from milkfat (kg/d) + milk protein (kg/d) yield.

Methane production

Methane emissions (g CH_4/cow/d) were measured using the sulphur hexafluoride (SF_6) tracer technique described by Johnson *et al*. (1994). Brass permeation tubes were orally placed in the rumen of each cow seven days prior to the measurement period and released the SF_6 marker gas at a known rate. Respired air was sampled continuously above the nose over four 24-hour periods via a fine bore capillary tube attached to an evacuated yoke strapped to the shoulder of each cow during both the indoor feeding and outdoor grazing, with analysis as described previously (Woodward *et al*., 2002; Woodward *et al.*, 2004). Methane production is expressed as total daily emissions (g CH_4/cow/d) that is important from a GHG inventory perspective. However, comparisons between treatments and between trials are best made using methane production expressed in terms of DMI (g CH_4/kg DM) to eliminate differences in methane production being assumed simply because cows ate more or less. Methane production is also expressed in terms of milk yield (g CH_4/kg milk) and milksolids yield (g CH_4/kg MS).

Statistical analysis

Data from the four measurement days in the short-term trial were averaged for individual cows and calculated treatment means compared using analysis of variance, including pre-trial data as a covariate for the milk data. Contrasts to test the effect of oil supplementation versus the control (no oil) and to test the linear and quadratic effects of increasing the proportion of FO in the oil mixture were included in the analyses. Data from the four measurement days in the long-term trial were averaged for individual cows and comparison of treatment means made by analyses of variance using GenStat.

TABLE 1: Short-term trial intakes (DMI), milk and methane production by groups of 8 cows given three oil treatments (500g/d) for 10 days prior to 4-day measurement period (see text for treatment details).

	No oil	Oil (g FO : g SFO)			sed
	(Control)	(0:500)	(75:425)	(150:350)	
Intake (kg DM/cow/d)	13.33	13.41	13.30	13.58	0.64
Milk yield (kg/cow/d)	22.10	22.19	23.45	24.27	1.10
Fat (%)	4.46	3.73	3.19	3.27	0.30
Protein (%)	3.19	3.08	2.99	3.01	0.05
Milksolids (kg MS/cow/d)	1.68	1.52	1.50	1.47	0.09
Total methane production (g CH_4/cow/d)	242.4	189.2	158.4	181.7	13.05
Methane per unit intake (g CH_4/kg DM)	18.49	14.47	12.09	13.79	1.08
Methane per unit production:					
(g CH_4/kg milk)	11.44	8.66	7.37	6.96	0.83
(g CH_4/k g MS)	150.81	129.39	117.76	110.87	10.79

RESULTS AND DISCUSSION

Methane emissions in the short- and long-term trials

The main findings from the short-term trial were that daily administration of 500g oil reduced methane production by 27% and increasing the proportions of FO in the SFO did not affect either methane production, DMI or milk production (Table 1). In contrast, the long-term trial involving oil administration for 12 weeks showed no effects on methane production or DMI (Table 2). Oils did affect milksolids production by reducing milkfat (P=0.0002) and protein (P=0.0011) concentrations in the short-term trial but had no effect on milk composition in the long-term trial. The nett effect was a significant reduction in milksolids (P=0.012) during the short-term trial (Table 1) but effects were not significant after 11 weeks of oil supplementation in the long-term trial (Table 2).

TABLE 2: Long-term trial intakes (DMI), milk and methane production by two groups of 10 cows given a daily dose of 300g oil after morning milking for 11 weeks and during the 4-day measurement period (see text for treatment details).

	Control	Oil	sed
Intake (kg DM/cow/d)	15.50	14.93	0.87
Milk yield (kg/cow/d)	23.14	23.83	1.41
Fat (%)	4.33	3.90	0.22
Protein (%)	3.40	3.28	0.11
Milksolids (kg MS/cow/d)	1.81	1.73	0.12
Total methane production (g CH_4/cow/d)	353.2	322.8	16.98
Methane per unit intake (g CH_4/kg DM)	23.01	21.67	1.01
Methane per unit production:			
(g CH_4/kg milk)	15.37	13.69	0.80
(g CH_4/kg MS)	196.56	190.43	11.63

It is not possible to undertake a statistical comparison of the two trials but the lack of a difference in methane production in the long-term trial did suggest an adaptation of the microflora to oil over the 11-week period prior to methane measurement. In many respects the two trials were similar – cows were in early lactation (54 and 78 days in milk respectively) and their diets were predominantly good quality pasture (Table 3) with 20.7 and 21.7% crude protein for the short- and long-term trials respectively. The fibre concentration in pasture grazed by cows during the measurement period of the long-term trial was 47% and higher than that in the short-term trial (42%) but these cows were given oil in a barley – linseed cake (1.2kg DM/cow/d) so dietary neutral detergent fibre (NDF) was 42% of DM in both trials.

TABLE 3: Chemical composition (g/100g DM, unless otherwise stated) of the perennial ryegrass-white clover based pasture fed to cows during the short- and long-term trials. Values are the mean of samples collected during the 4-day measurement periods.

	Short-term	Long-term
Dry matter (%)	16.6	18.3
Crude protein	20.7	21.7
Lipid	4.1	4.4
Acid detergent fibre (ADF)	22.4	21.9
Neutral detergent fibre (NDF)	42.0	47.1
Soluble sugars and starch	13.4	17.1
Metabolisable energy (MJ/kg DM)	11.7	10.9

The methane production from the control cows in the short-term trial was much lower (242g CH_4/cow/d; 18.5g CH_4/kg DMI) than in the long-term trial (353g CH_4/cow/d; 23.0g CH_4/kg DM) and this difference is not easily explained. The values are within the ranges reported for dairy cows fed pasture-based diets in previously published trials. Robertson & Waghorn (2002) reported values of 18.0, 22.2 and 23.8g CH_4/kg DM over a lactation, while other values include 24.6g CH_4/kg DM (Woodward *et al.*, 2002), 24.2g

CH_4/kg DM (Woodward *et al.*, 2004), 21.7g CH_4/kg DM (Lee *et al.*, 2004), 16.3g CH_4/kg DM (Waugh *et al.*, 2005). The current emissions standard for dairy cows grazing pasture used in the New Zealand inventory is 21.6g CH_4/kg DM (New Zealand Climate Change Office, 2003).

We are aware of doubts surrounding the use of alkane indigestible markers for estimating DMI (Waghorn *et al*., 2004) and errors could affect the methane emissions from the long-term trial expressed in terms of DMI. However in this instance the DMIs calculated using alkane markers were very similar to estimates based on feed requirements calculated from cow liveweight, liveweight changes, milk production and composition, and metabolisable energy (ME) values for feeds (Holmes *et al*., 2002).

In addition to total emissions, expressing methane on the basis of milksolids production can provide an indication of the GHG cost in relation to production. The short-term trial provided clear benefit of oils for lowering g CH_4/kg MS from 151 to 119 (P=0.0013) but after 11 weeks of oil supplementation effects were very small (control: 197 vs. oil: 190g CH_4/kg MS; P=0.604).

Oils and methanogenesis

Oils can reduce methanogenesis by acting as a sink for hydrogen ions or by affecting changes to the microflora responsible for methane production. Unsaturated oils or fats should always reduce methane production because the process of rumen bio-hydrogenation (creating harder fats) provides a sink for hydrogen ions derived from fermentation, thereby reducing the amount of hydrogen available for methane production (Czerkawski *et al.*, 1966). The linseed oil used in the long-term trial reported here contained a high concentration of linolenic (62%) with 16% linoleic and 13% oleic fatty acids, having the capacity to bind 6, 4 and 2 hydrogen atoms, respectively (ie. 2 for each double bond that becomes saturated). Stoichiometric calculations would indicate that saturation by hydrogen in 200g of linseed oil should remove (200 / 280) x 4.6 = 3.3 moles of hydrogen, which is equivalent to 0.82 moles of methane, or approximately 13g CH_4/d. The type and quantity of oil given to cows will affect the extent of hydrogen removal, but values would be relatively small and may not be detected using the methodology and trial designs reported here.

Reports of reductions in methane production have ranged from 20 to 70% with oils containing medium chain fatty acids eg. lauric and myristic acids in coconut oil (Machmuller & Kreuzer, 1999; Machmuller *et al*., 2000; Machmuller *et al*., 2001) or long chain fatty acids in fish oil eg. eicosapentaenoic (C20: 5n-3; EPA) and docasahexaenoic (C22: 6n-3; DHA) acids. Fievez *et al*., (2003) investigated the effects of fish oil with differing concentrations and proportions of EPA : DHA on methanogenesis *in vitro* and suggested an 80% methane suppression was possible without affecting digestion. They suggested EPA and DHA were toxic to methanogens but results were inconsistent and speculative.

Interpretation of methane mitigation effects of oils should be undertaken with care. The reductions observed *in vitro* (Dong *et al*., 1997; Fievez *et al*., 2003; Hess *et al*., 2003) appear to be much greater than reports from animal trials, and *in vivo* mitigation using chlorated compounds or anitibiotics does diminish over time (Cole & McCroskey, 1975; Clapperton, 1977; Fellner *et al*., 1997). Unfortunately reports of long-term studies when oils have been given to dairy cows, such as the one reported here and Johnson *et al*. (2002) have not measured methane emissions soon after commencement of the oil treatment, so we do not know if an initial reduction was achieved and diminished over time or whether no reduction occurred at any time. Nevertheless, from a practical perspective, if oils do not achieve a persistent mitigation effect then application on-farm will only be successful if they also benefit production.

Oils for dietary supplementation

Long-chain fatty acids in oils are absorbed efficiently and provide twice as much gross energy as carbohydrate in ruminant diets. Increasing dietary energy density is an attractive option for producers, especially as ryegrass-white clover-based pasture contains only 3-6% lipid, of which up to 50% are indigestible waxes. However, Boadi *et al*., (2004) emphasized the need for caution when using oils as a methane mitigant because excess lipid (over 5-6% of DMI) will suppress fibre digestion and DMI. In the short-term trial conducted here, oil supplementation had no effect on DMI (Table 1) and the lower level of supplementation given in the long-term trial was not detrimental to DMI (Table 2), but in neither trial did oil benefit production.

CONCLUSIONS

The main conclusion from this work is that oil supplementation did not result in a consistent reduction in methane emissions or benefit in cow productivity. The short-term trial showed that a reduction in methane emissions could be achieved without suppressing DMI but the long-term

supplementation suggested mitigation to be either variable or not sustainable. These trials demonstrated the importance of long-term evaluation of potential mitigants under practical farming conditions and the need to examine the economic impact of mitigation strategies. Furthermore plant-derived oils from annual crops eg. canola oil, will generate substantial GHG emissions from soil cultivation and machinery use during crop production and harvesting (Van der Nagel *et al.*, 2003). It is important to consider the "whole picture" in any GHG mitigation strategy. The lack of any benefit from oil supplements on milksolids production in both the short- and long-term trials will preclude its use to increase production and reduce methane emissions on New Zealand dairy farms.

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