Focus Areas - Section 6

Reducing Emissions

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Reducing nitrous oxide emissions following slurry and fertiliser applications

Suzanne Higgins

Figure 1: Apply slurry via a low trajectory spreading technique to reduce nitrogen loss and improve efficiency

Key Messages

- Nitrogen is one of the most important nutrients for crop growth but is easily lost from soil through leaching and gaseous emissions.
- As much as 30-50% of applied nitrogen can be lost from soil, depending on timing of application, rate of nitrogen applied, type of fertiliser and method of application.
- To minimise nitrous oxide emissions, leaching and surface runoff, avoid applying slurry or fertiliser if heavy rain is forecast in the days immediately following application.
- Low trajectory slurry spreading techniques such as trailing shoe are recommended.

Background

Nitrogen is one of the key nutrients for optimum yields of grassland and arable crops. However, nitrogen can be very easily lost from soil through leaching or via gaseous emissions to the atmosphere. Gaseous emissions of nitrogen include ammonia (NH_3) and nitrous oxide (N_2O). Nitrous oxide is a very potent greenhouse gas and emissions can be particularly high following the application of nitrate-dominated fertilisers such as calcium ammonium nitrate (CAN). However, the loss of nitrogen as N_2O can be reduced or minimised through careful management. This is extremely important considering the cost of inorganic fertilisers, in addition to the environmental impact.

Research Studies

AFBI has conducted several research studies measuring and comparing N_2O emissions following commonly used nitrogen fertilisers such as CAN, Urea and Protected Urea, along with compound fertilisers such as 24-6-12, 20-10-10 and liquid N fertiliser.

Research Findings

There are a number of important, interacting factors that influence nitrogen loss from soil. These include:

- **Timing of Application**
  Heavy, prolonged rainfall in the 24-36 hours following fertiliser or slurry applications is one of the biggest drivers of N_2O emissions. To minimise losses, be mindful of weather conditions and avoid applying fertiliser or slurry if heavy rain is forecast.

- **Fertiliser Type**
  N_2O emissions can occur following both slurry and inorganic fertiliser applications. Emissions are greatest following application of high-nitrate fertilisers such as CAN, applied to wet, warm soils. Loss of N_2O would be lower following urea-based fertilisers, but urea-based fertilisers are more at risk of contributing to ammonia emissions, which is equally undesirable.

- **Rate of Nitrogen Applied**
  The higher the rate of nitrogen applied, the greater the risk of nitrogen loss.

- **Method of Application**
  By placing slurry closer to the ground surface and reducing contact with the air, low trajectory spreading techniques such as trailing shoe can reduce nitrogen losses following slurry application, improve nitrogen use efficiency and potentially increase yields by as much as 25% (Figure 1).

Potential Impact for Farming for the Future:

Minimising nutrient loss and improving nutrient use efficiency is key to ensuring the long-term economic and environmental sustainability of farming practices. However, this can be very difficult to achieve. Recent trends towards volatile and unpredictable weather make it very challenging for farmers to reduce both N_2O and NH_3) emissions. However, as far as possible, farmers should stick to windows of good weather for applying nutrients, as this can go a long way in terms of reducing loss.

Acknowledgement:

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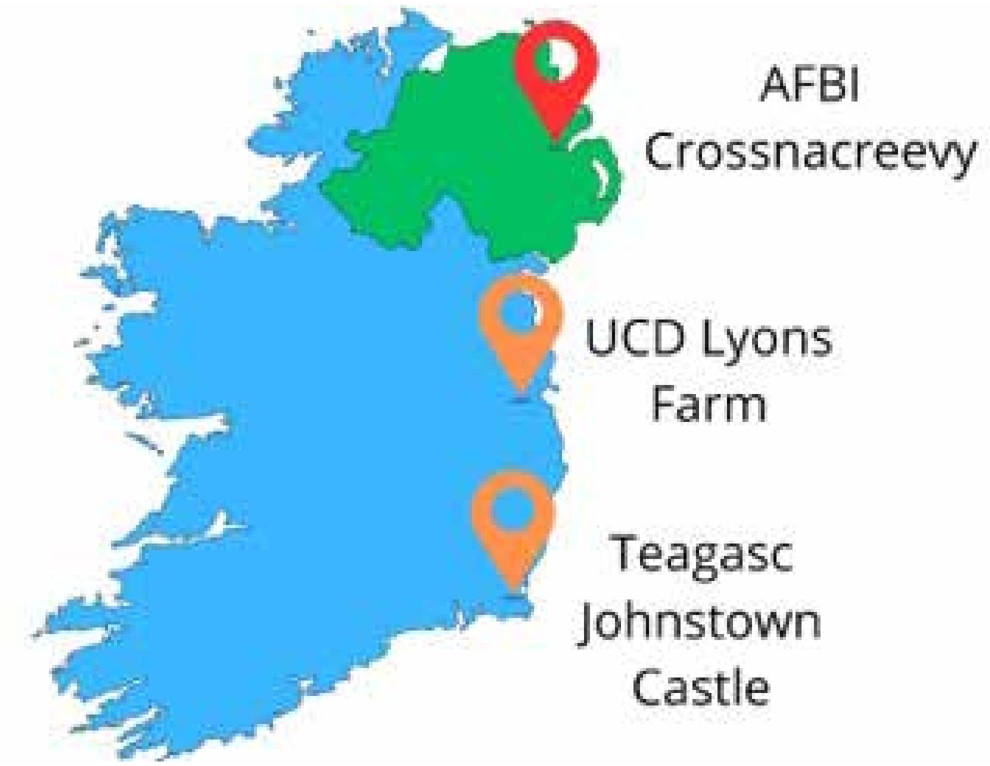
Multispecies Grasslands: Influence of Mixture Composition on Nitrous Oxide Emissions and Nitrogen Use Efficiency

Danielle Varley

Harnessing Biodiversity for Sustainable Agriculture



Key Messages

- Synthetic nitrogen (N) fertiliser provides readily available forms of N that can be taken up by plants; however, this available N can be easily lost through surface runoff, leaching and as gaseous forms, such as nitrous oxide (N_2O).
- N_2O is a potent greenhouse gas with over 270 times the warming potential of carbon dioxide.
- Multispecies grassland swards, comprised of grasses, legumes and herbs, have recently gained traction as a potential solution to decrease N_2O emissions and improve N use efficiency.

Background

The Multi4More project is a DAERA-DAFM funded research collaboration between AFBI, Teagasc, UCD and TCD. A common field experiment was established at AFBI Crossnacreevy, Teagasc Johnstown Castle and UCD Lyons Farm. The project aims to evaluate the ability of multispecies grasslands sward to reduce synthetic N fertiliser use and N_2O emissions, while improving N use efficiency without a loss in yields.

Multispecies grassland swards have the potential to:

- Reduce greenhouse gas emissions,
- Produce higher yields at lower N input compared to grass monocultures,
- Enhance animal performance,
- Improve soil fertility,
- Build tolerance to environmental disturbances, such as drought.

However, research is required to generate N_2O emission factors for multispecies mixtures grown in Irish soil and climatic conditions. Legumes, such as white and red clover, are capable of fixing N from the atmosphere, which is then shared with neighbouring plants. While herbs, like plantain possess compounds that can inhibit a N_2O production pathway. Additionally, herbs such as chicory can enhance yield productivity.

Research Studies

In May 2023, 111 experimental plots were established at AFBI Crossnacreevy to assess N_2O emissions and yield of multispecies grassland swards.

Experimental plots were sown with varying proportions from 0 to 1 of perennial ryegrass, timothy, white and red clover, plantain and chicory. The N fertiliser treatments under study are 0, 75, 150 and 300 kg N ha-1 yr-1. In April 2024, measurements of N_2O emissions began and will continue for two years until 2026 to calculate the emission factor of various species compositions. Five harvests are carried out annually to assess agronomic properties, such as dry matter and N yield.

Potential Impact for Farming for the Future

Multispecies grassland swards have the potential to lessen dependency on synthetic N fertiliser while producing comparable yields to high N fertiliser input grass monocultures. Multispecies can also enhance tolerance due to weather variations brought on by changes in the climate. Additionally, multispecies swards may be able to lower greenhouse gas emissions and nutrient leaching, thereby supporting sustainable agricultural practices.

This project was funded by DAERA and DAFM

Reducing emissions in dairy, beef and sheep production systems

O Cristobal Carballo, X Chen and T Yan

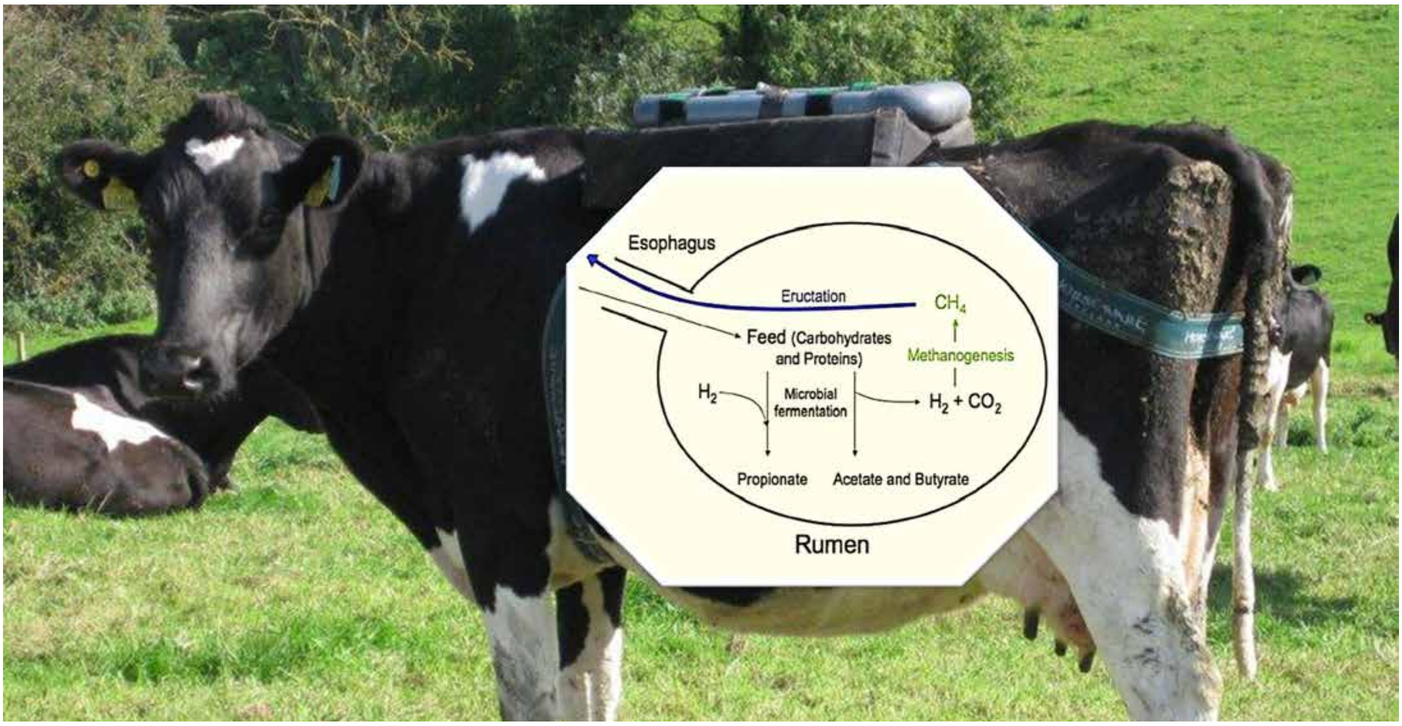


Figure 1: Methane production the the rumen

Key Messages

- Methane is a key greenhouse gas (GHG) from agriculture. AFBI has been leading research in methane emissions from ruminants since 1992.
- Currently AFBI has an extensive programme of research ongoing investigating the effectiveness of a large range of dietary strategies, including dietary additives to reduce methane and ammonia emissions.
- Dietary approaches to reducing methane have been found to have varying degrees of success. Inhibitors show much promise albeit how to implement in grazing systems remains a challenge and cost.
- AFBI's work directly contributes to the national database on methane emissions and is used to update the UK's GHG emission inventories.

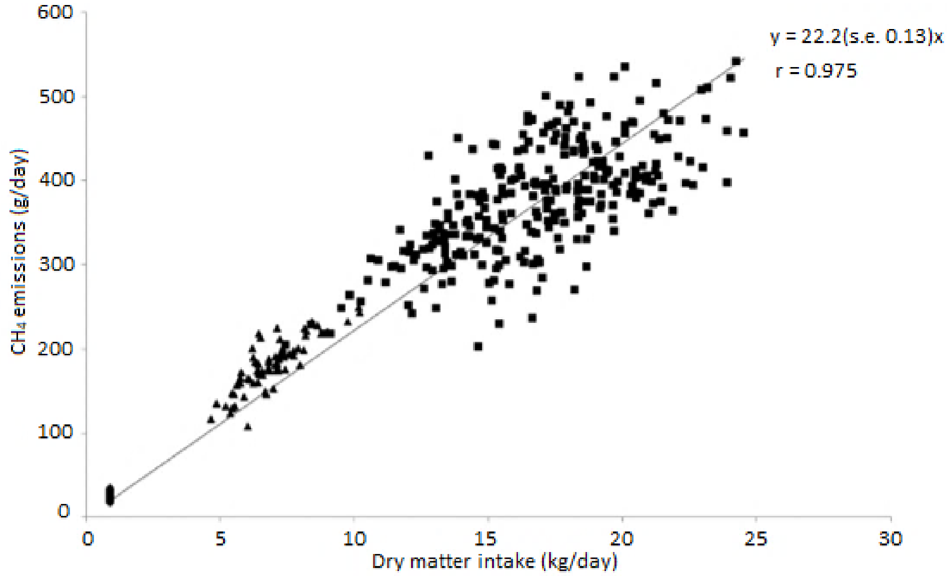
Background

The UK has committed to net zero carbon by 2050. Achieving these ambitious targets requires the development of accurate estimates of greenhouse gases (GHG) and mitigation strategies for specific farming conditions. Methane is naturally produced by cattle/sheep and is of major interest due to its significant contribution to GHG emissions. Methane also represents an energy loss of 6-12% to the animal and as such a reduction in methane production in the animal should increase the amount of energy available to the animal for meat and/or milk production.

As well as reducing methane, the UK has the obligation to achieve a 16% reduction on its ammonia emissions by 2030 in comparison to 2005 levels. High atmospheric ammonia levels have a significant negative impact on biodiversity, as well as human and animal health. From the ammonia inventories in NI, approximately 96% of NI's ammonia emissions are attributed to the agricultural sector, with 70% allocated to the

Figure 2. Observed dry matter intake and methane emissions per day.

Sheep (♦; n = 288), beef cattle (▲; n = 71) and dairy cows (■; n = 284) included in the analysis (Adapted from Bell et al., 2016).



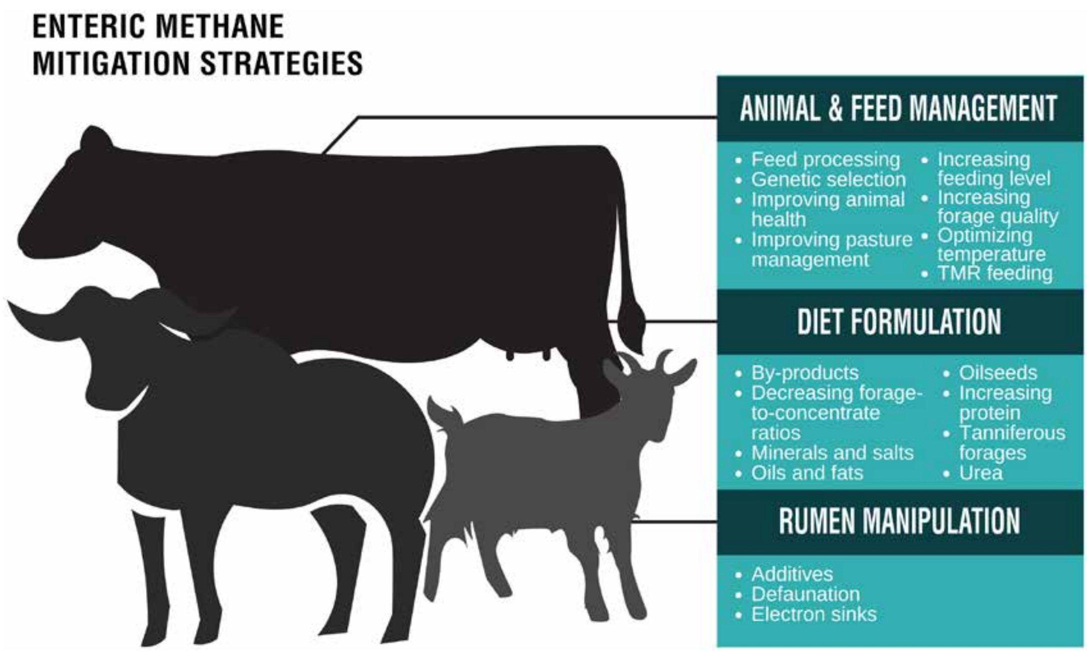
livestock sector. Ammonia is created when urine and faeces mix, which occurs on a much greater scale when livestock are confined within housing systems. Therefore, it has been suggested that a starting point for achieving ammonia abatement in the ruminant sector must be the management of livestock through increasing outdoor grazing followed by reducing the nitrogen loss in urine and faeces.

Over the past 30 years AFBI Hillsborough has been investigating how we can improve the efficiency of utilisation of energy and nitrogen, reduce enteric methane emissions and the team have also been exploring relationships between energy, methane and nitrogen flow in livestock systems. Through this work and that of others a range of strategies have been proposed, are underway or completed to reduce both methane and ammonia emissions.

What are the dietary strategies to reduce methane emissions?

The consumption of feed by livestock is directly associated with their methane emissions as shown in Figure 2. However, as illustrated in Figure 3, there are many strategies to reduce methane emissions, with feed composition and its quality a key approach. More recently much hope has been placed on the role of dietary methane inhibitors to reduce overall methane emissions. Many inhibitors show promise, but if these feed additives are to become part of a successful abatement strategy for national agricultural systems, it is essential that they are shown to be effective both indoors and on pasture-based systems.

Figure 3.



Arndt, et al., 2022. https://doi.org/10.1073/pnas.2111294119

Since 1992, AFBI has undertaken more than 80 studies (the majority in dairy cows) evaluating the effects of a range of dietary, animal and management factors on methane emissions from livestock under a range of farming conditions. Over these studies the average yields of methane recorded in AFBI respiration calorimeters in dairy cows, growing cattle and sheep were 358 (124 - 582), 170 (68 - 291) and 23 (7 - 42) g/day, respectively. The corresponding data in methane emissions per kg DM intake are respectively 22.3 (10.9 - 30.2), 24.0 (11.7 - 33.9) and 19.7 (10.6 - 33.9) g/kg. Methane emissions from individual cattle or sheep vary considerably, because the emission not only relates to total feed intake, but also is influenced by animal genetics and a range of other dietary factors supporting targeting these as mitigation strategies.

Table 1 Effect of silage quality with TMR diets on methane emissions

	HIGH QUALITY	LOW QUALITY
Chemical composition		
Organic Matter (%DM)	92.6	92.9
Crude Protein (%DM)	17.2	14.4
Indigestible fibre	7.2	11.4
Nutritional Values		
Metabolic energy (MJ/kg of DM)	11.3	10.5
Metabolic protein	96	88
Methane		
Grams per kg of Milk (g/kg)	14.1	15.4

9.2% Methane increase

Findings from methane reduction research studies

Below are a just few examples of how dietary approaches can influence the methane emissions from ruminant livestock.

Improved diet quality

Higher fibre diets are associated with increasing methane production per kg of DMI; on the other hand, increases in starch concentration reduces the methane produced in the rumen per kg of DMI. This effect on diet quality is clearly shown in Table 1 with a TMR diet based on lower quality silage delivering 9.2% higher methane emissions per kg of milk. Focusing on grass, many factors can influence the nutritional quality of grass consumed by livestock be that grazed or when ensiled, such as: grass variety, sward composition, management practice, maturity at harvest and fertiliser management.

Examples of grass quality factors known to affect enteric CH_4 output:

Fibre (NDF) content: Grasses with high NDF (neutral detergent fibre) content decrease dry matter intake due to the negative relationship between the NDF content of feeds and the rate at which they are digested. The ratio between digestible fractions (such as sugar) and non-digestible fractions (such as indigestible NDF) is also important.

Fat content: Recent research from New Zealand is indicating that new genetically engineered ryegrass cultivars with greater concentrations of fat in the leaf may be a potential alternative to reduce methane emissions (Beechey-Gradwell et al., 2022). Laboratory results from in vitro studies of these new cultivars, used either fresh or ensiled, showed to have higher gross energy and to produce up to 10-15% lower methane emissions (Winichayakul et al., 2020).

Digestibility (DOMD - digestible organic matter): AFBI research indicated that for every 1 unit increase in grass digestibility, methane emissions from a grazing dairy cow producing 8000kg of milk per year reduced by ~1.8% .

Diet composition

Diet quality and composition are often interlinked but the type and combination of dietary components can influence how the total diet is digested and utilised. AFBI researchers have conducted several studies in these areas such as altering concentrate to forage ratios or substituting grass/ grass silage for alternatives. Below is example of a study where different types of clover were introduced into the diet.

Dietary inclusion of white clover in sheep

A zero-grazed herbage study with Texel ewe hoggets investigated the effects of dietary inclusion of white clover on feed intake, digestibility and enteric methane emissions. The

Table 2. Intake, body weight, digestibility and methane emissions of ewes supplemented with white clover.

	TREATMENT		
	Grass	MLS	LLS
DM intake (kg/d)	1.33	1.45	1.46
Final BW (kg)	68.5	68.6	68.8
DM Digestibility (g/kg)	790	788	783
Gaseous exchange			
Methane emissions			
g/d	35.6	37.6	37
g/kg BW	0.52	0.55	0.54
g/kg DMI	27.3	26.5	25.7
Hydrogen (g/d)	56.0	68.3	76.1

diets were (DM basis): 100% perennial ryegrass (PRG, Control), 70% PRG and 30% medium leaf size white clover (Chieftain, MLS), and 70% PRG + 30% large leaf size white clover (Barblanca, LLS). Results (Table 2) showed dietary treatments had no significant effect on DM intake, final body weight or DM digestibility. Dietary treatment also had no significant effects on daily methane emissions, or methane emissions per kg of DM intake or body weight. In conclusion, feeding white clover had no significant effect on feed intake, DM digestibility or methane emissions in sheep. However, through the inclusion of clover in swards, N application from inorganic fertilizer can be reduced and in turn the nitrous oxide emissions (a very potent greenhouse gas) from swards can be reduced significantly.

Dietary additives/supplements

The impact of dietary additives/supplements on methane emissions is largely through:

- Inhibiting or manipulating the microbial community in the rumen to reduce hydrogen formation therefore hydrogen less available to form CH_4
- Utilising hydrogen by alternative pathways to CH_4 formation.
- Inhibiting methanogens in the rumen preventing synthesis of CH_4

A number of the additives that fit those modes of action in reducing methane include those based on seaweeds, halides, tannins, oils, nitrates, and 3-NOP. A few examples of studies conducted by AFBI and others investigating the effectiveness of such additives below.

Microalgae supplementation in finishing lambs

Two studies, using Texel crossed male lambs, were conducted at AFBI Hillsborough to investigate the effects of supplementing microalgae on animal performance, ruminal fermentation, methane emissions, and feed digestibility in finishing lambs . Treatments consisted of TMR diets with 50:50 grass silage and concentrate (DM basis). Microalgae in study one included the dehydrated cell and in study two the extracted oil. In both studies, diets were adjusted to include microalgae oil on a DM basis at: 0.00% (Control), 0.54% (Low), 1.08% (Medium) and 1.62% (High).

High levels of microalgae decreased feed intake by up to 19% and daily weight gain by approximately 22.5% compared to control lambs. However, the intake of high levels of the extracted microalgae oil reduced methane production by 21.5% and methane per kg of feed intake by 20.3% compared to control lambs. Digestibility of DM, organic matter, and energy were improved in lambs receiving high levels of dehydrated microalgae, without any adverse effects when fed with microalgae oil. Ruminal fermentation was affected in both studies; but this does not affect feed efficiency or residual feed intake.

We concluded that microalgae supplementation at high levels can reduce methane emissions, without effecting nutrient digestibility and feed

Table 3 Performance and methane emissions of dry ewes supplemented with calcium peroxide in the concentrate diet.

	CONTROL	MEDIUM	HIGH
Total DM intake (kg/d)	1.99	2.04	1.97
Silage DM intake (kg/d)	1.59	1.63	1.56
Conc. DM intake (kg/d)	0.40	0.41	0.41
Daily liveweight gain (kg/d)	0.173	0.175	0.158
Methane (g/d)	48.2	47.0	42.9

Table 4 Effect of supplementing 3-NOP in the roughage or in the concentrate of lactating dairy cows

	CONTROL	3-NOP IN ROUGHAGE	3-NOP IN CONCENTRATE
Dry matter intake (DMI; kg/d)	22.5	21.3	22.3
Milk production (kg/d)	28.2	26.7	28.0
Methane production (g/d)	525	-28%	-23%
Methane per kilo of DMI	23.5	-23%	-21%
Methane per kilo of milk	18.5	-24%	-22%

Van Wesemael et al., https://doi.org/10.3168/ jds.2018-14534

efficiency; however, it likely requires a long-term adaptation period due to the reduced feed intake and growth observed in the first weeks of supplementation. Overall, further work is required to investigate its effect when fed for a longer period of time.

Supplementation of calcium peroxide to dry ewes

A study using lowland crossbred dry ewes examined the effect of supplementing calcium peroxide in the diet to reduce methane emissions and assess animal performance. Calium preoxide was added to the concentrate pellets (on a DM basis) as follows: control (0.0%), medium (5.0%) and high (7.5%). Ewes had free access to grass silage, and the amount of concentrate fed represented 20% on a DM basis. Results (Table 3) showed reductions of 11% in methane production when ewes were supplemented with high doses of calcium peroxide when compared to control ewes. The intake of the additive did not affect DM intake or the weight of dry ewes. In conclusion, the inclusion of the calcium peroxide at the highest dose reduced methane production significantly.

Supplementing 3-Nitrooxypropanol (3-NOP) to dairy cows

Numerous studies have been conducted globally investigating the effect of 3-NOP inclusion in ruminant diets on emissions, performance, animal and food safety. The commercial product is now becoming licenced and available for use by specific animal types in more countries globally. An example of one such study conducted in Belgium showed a >20% reduction in methane emissions with no loss in milk yield (Table 4). A recent review led by researchers in the USA of 14 studies worldwide on 3-NOP inclusion found that although effectiveness is influenced by diet quality (fibre and fat level) on average 3-NOP inclusion reduced methane emissions per kg of milk by 32.6 %. These high reductions are largely observed with TMR/indoor diets with more challenges at grazing.

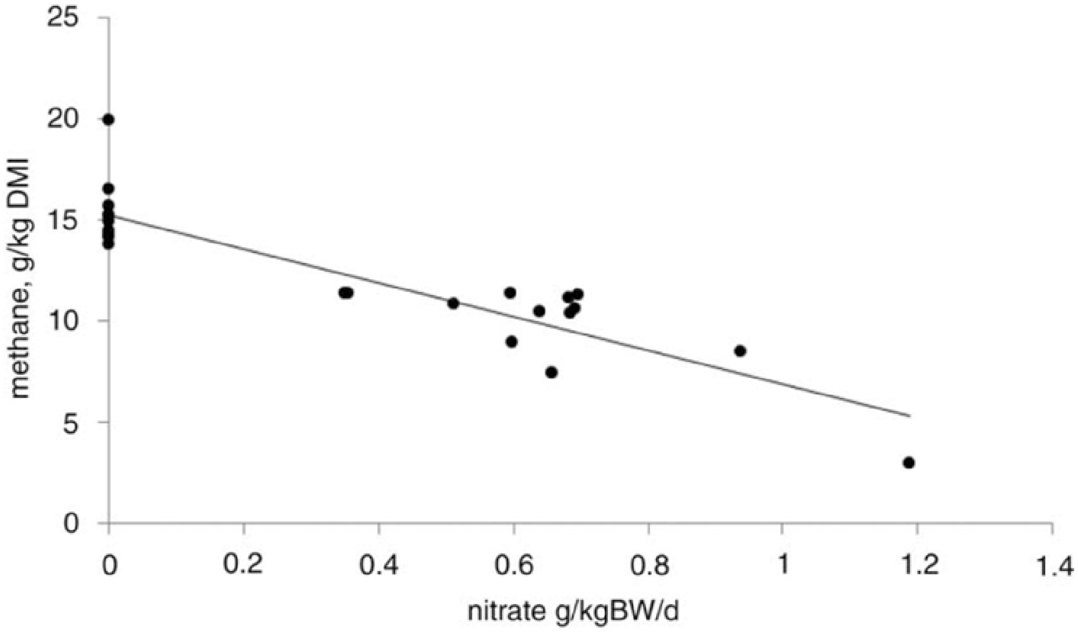


Figure 4. Enteric methane emissions responses to increasing levels of nitrate in ruminant animals (beef cattle, dairy cows, and sheep) from 8 studies and 25 treatments (Figure adapted from Lee and Beauchemin, 2014).

Nitrate example

Prompted by the growing concern over global warming, nitrate supplementation has received special attention as a supplement that mitigates enteric methane emissions. Nitrate is a feed additive with an effective and persistent action over time on reducing enteric methane emissions. International studies in cattle and sheep have shown that enteric methane production per kg of DMI decreased as the intake of nitrate per kg of BW increased (Figure 4).

One of the requirements for an effective mitigation strategy is a persistent efficacy in lowering enteric methane emissions. In dairy cows, the addition of nitrates (2.1% of dietary DM) in diet consistently reduced methane production up to 16.5% for 90d. Similarly, in sheep diets in which urea was replaced by nitrate (0.88 g nitrate kg−1 BW and 2.7% nitrate of dietary DM) methane production decreased up to 30% when compared to those with urea.

Despite the significant reductions in methane production, nitrate toxicity in ruminants has been reported in several international studies. The major factors causing nitrate toxicity: (1) nitrate levels in the diet, (2) nitrate consumption rate, (3) incomplete nitrate and nitrite reduction to ammonia in the rumen, and (4) slow rumen passage rate. The potential for toxicity of nitrate (nitrite) can be reduced by acclimatizing animals to nitrate gradually and precision feeding.

Feeding seaweeds to dairy cows

Researchers in the USA when supplementing beef steers with *Asparagopsis taxiformis* (Red Seaweed) reduced enteric methane emissions by up to 80% with interactions with diet type/quality. This red seaweed is typically found in tropical to warm temperate waters.

AFBI using a brown seaweed (and its extract) local to Ireland evaluated the impact on animal performance, rumen fermentation, nutrient digestibility and methane emissions in lactating cows. Late lactation multiparous Holstein-Friesian cows were fed 3 TMR diets; each contained (DM basis) 40% concentrates and, respectively, (1) 60% grass silage (Control), (2) 56% grass silage and 4% whole seaweed (dried *Himanthalia elongata*, Whole Seaweed) and (3) 56% grass silage and 4% seaweed extract (*Himanthalia elongata* extract, Seaweed Extract). Dietary inclusion of seaweed or seaweed extract did not affect DM intake, milk yield or milk composition, or methane emissions (Table 5- next page).

However, the inclusion of seaweed and seaweed extract increased N intake up to 12% and decreased the proportion of N excretion in urine up to 29%. In conclusion, while some seaweed have been found to reduce methane emission, in this work, the dietary inclusion of this seaweed species or extracts from it did not affect DM intake, milk yield, milk composition, DM digestibility or methane emissions of lactation

Table 5. The effect of dietary inclusion of seaweed or seaweed extract on feed intake, milk yield, gas emissions and N digestibility.

	TREATMENT		
	CONTROL	WHOLE SEAWEED	SEAWEED EXTRACT
Animal measurement			
DM intake (kg/d)	24.6	23.8	23.5
Milk yield (kg/d)	31.1	30.1	31.2
Milk composition (%)			
Protein	3.7	3.7	3.73
Fat	4.95	5	5.25
Lactose	4.66	4.67	4.67
Methane emissions			
g/d	482	481	476
g/kg DMI	19.7	20.2	20.3
g/kg MY	15.8	16.2	15.4
N intake and output (g/d)			
N intake	656[a]	716[b]	744[b]
Faecal N output	228	218	233
Urinary N output	258[b]	217[a]	243[b]
Manure N output	485	435	476
N utilisation efficiency (g/g)			
Faecal N:N intake	0.347	0.304	0.311
Urinary N:N intake*	0.393[b]	0.304[a]	0.327[a]
Manure N:N intake*	0.740[b]	0.608[a]	0.638[a]
Urinary N:Manure N	0.532	0.500	0.515

*Data points with the same superscripts are not different from each other

dairy cows. However, feeding this seaweed or its extracts altered nitrogen excretion with less urine nitrogen output, which could result in less nitrous oxide and ammonia emissions from slurry.

Ammonia emissions from grazing dairy cows

With all dietary strategies to reduce methane these must be developed to also not increase but ideally reduce ammonia emissions. Within the recent AFBI *Himanthalia elongate* study, nitrogen losses to the environment were reduced, which would then deliver reduced ammonia emissions. Current studies within the dairy group are showing the major improvements in nitrogen use efficiency and reduced ammonia emissions by reducing diet protein content (whilst still meeting the animals metabolizable protein requirements). Ammonia is formed when urine and faeces mix, therefore emissions whilst grazing are lower and extending the grazing season is a possible ammonia mitigation strategy.

AFBI recently assessed ammonia emissions at of lactating dairy cows grazing (Figure 5). Cattle were managed using two stocking grazing rates: normal and high. Circular plots were constructed and grazed for 4 - 5 consecutive days. Ammonia measurements were taken during the early, middle and late grazing season. Ammonia production (g/LU) in the high stocking grazing management showed a more than double fold increase by the 3rd and/or 4th day of grazing during the early and middle grazing seasons, while a 1.25 increase was observed in the late season when compared to the normal stocking rate (Table 6). By day 6, ammonia production remained higher than 50 g/LU in the high grazing stocking, while the normal stocking rate showed emissions below 50 g/LU.

Figure 5. Cows grazing with an integrated horizontal flux tower capturing emissions.

Table 6. Ammonia emissions (g) per live unit (LU) in grazing lactating cows using two stocking rates during three different grazing periods.

	EARLY (MAY 2022)		MIDDLE (JULY 2022)		LATE (SEPTEMBER 2022)	
DAY	NORMAL	HIGH	NORMAL	HIGH	NORMAL	HIGH
1	0.00	45.62	33.75	45.37	5.85	61.49
2	54.73	37.15	44.23	72.17	92.71	98.25
3	78.78	--	66.02	115.02	127.27	165.06
4	80.78	162.58	74.07	--	131.09	167.41
5	14.92		35.59	110.61	29.98	108.96
6	15.43	50.18	--	73.79	47.02	90.81
7	--	3.29	--	14.96	25.92	5.5

Normal Stocking Rate: grass DM intake allowance at 2.4% of group's BW

High Stocking Rate: grass DM intake allowance at 1.8% of group's BW

Missing values correspond to rainy days with strong winds

Research findings

- Many dietary approaches are available now that reduce methane emissions from ruminant livestock whilst maintaining or increasing animal productivity.
- AFBI research has identified a range of effective methane-reduction factors possible now, such as: selection of highly efficient animals, improving dietary ME concentration, feeding good quality forage and dietary manipulation for balanced supply of protein and energy.
- Much research ongoing within AFBI and internationally on dietary methane inhibitor additives. Many additives show promise with approx. 20-30% reductions in methane possible; however, the challenge remains on achieving these levels of reduction in grazing systems and costs.
- All dietary approaches to reduce methane emissions must not increase but ideally reduce ammonia emissions. As an example AFBI research found the inclusion of brown seaweed/seaweed extract in the diet of dairy cattle as a proposed methane inhibitor did not reduce methane but had positive impacts on nitrogen losses in urine and therefore ammonia emissions.
- AFBI research has quantified the impact of stocking rates of grazing dairy cows on ammonia emissions throughout the grazing season.

Potential Impact for Farming for the Future

Overall, through a combination of dietary approaches available now to reducing methane emissions and the potential of direct methane inhibitors additives, the future farm is expected to have a range of tools to significantly reduce methane emissions.

These approaches will not be silver bullets to address greenhouse gas emissions but will help reduce emissions. Challenges remain in how inhibitors can be incorporated and be effective in grazing systems and costs given many inhibitors do not enhance productivity. Much research is ongoing in AFBI and globally to address these challenges.