Feed-based strategies to reduce methane emissions from milk and meat production

CONTENTS

Introduction

European agriculture is responsible for 11% of direct greenhouse gas (GHG) emissions [1]. Methane (CH_4) from the enteric fermentation of cattle is the most important source of emissions and accounted for 69% of agricultural GHG emissions in 2020 alone [2]. The global warming potential (GWP100) of CH_4 is around 28 times higher than that of CO_2, but it also has a shorter half-life in the atmosphere and is broken down more quickly than CO_2 [3]. Methane is produced, among other things, during fermentation processes, especially of fiber-rich feed components in the rumen of ruminants (see box "Formation of methane in cattle"). On the other hand, it is precisely this digestive process that gives ruminants their special position in food production, as they utilize biomass that is not edible for humans and convert it into high-value protein (milk and meat) for human consumption. Due to their special digestive system, ruminants have the potential, in contrast to monogastric animals, not to induce food competition with humans. With an intensification of production, which is often accompanied by higher proportions of concentrate feed (cereals and protein crops) in the ration, the main advantage of the digestive system of ruminants is nullified and only the disadvantages, i.e. CH_4 emissions, remain. Even if an increase in the proportion of concentrate feed would lead to a slight decrease in CH_4 emissions, the disadvantages of such a system would clearly outweigh its advantages. Therefore, all feeding measures proposed in this factsheet are within a framework in which the carbon cycle is closed and competition with human nutrition is low.

Introduction

The formation of CH4 in the digestive tract of ruminants is unavoidable and necessary for the specialized digestive processes of plant fibre components. **Nevertheless, efficient measures to reduce enteric CH_4 emissions are urgently needed**. The primary approach to reduce CH_4 production from dairy and beef production is therefore feed-based measures. A distinction can be made between feeding strategies, e.g. the use of certain feedstuffs, ration design and the targeted use of CH_4-inhibiting feed additives. However, it is important to bear in mind that methane-reducing feeding only has a limited effect and that a combination of different measures at farm and management level (herd and manure management) is required to reduce emissions across the entire farm and close the carbon and CH_4 cycle (Fig. 1). Nevertheless, it is worth starting with measures before and during feeding, as CH_4 that is not produced in the first place does not have to be reduced later.

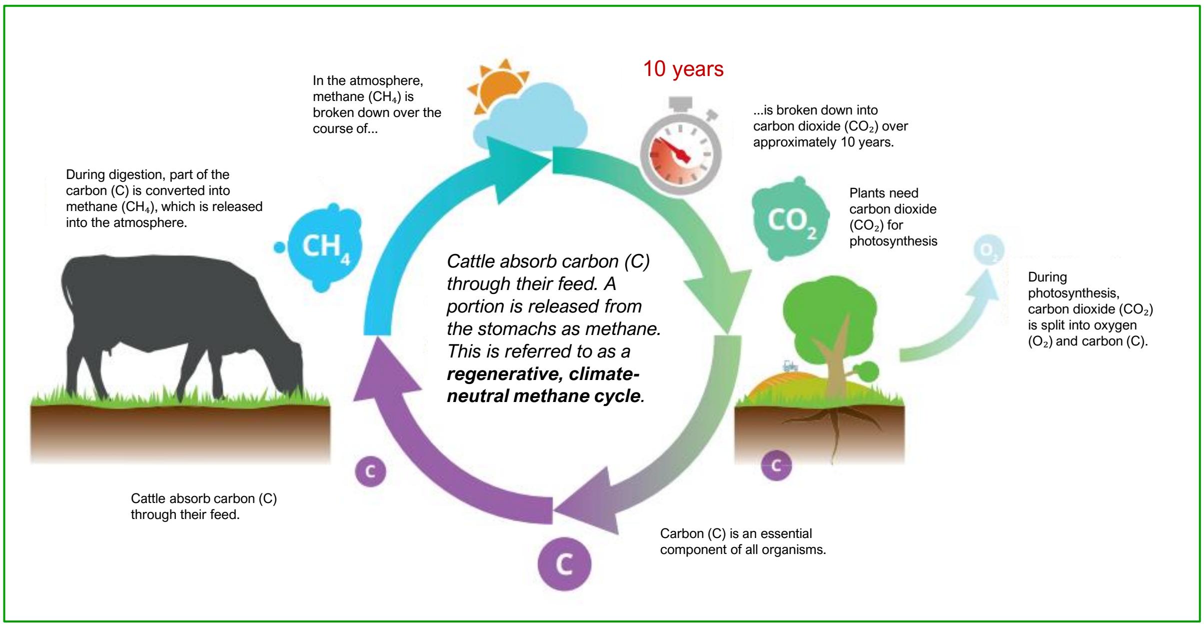

Figure 1: Regenerative methane cycle in cattle feeding [7].

The aim of this data sheet is to provide an overview and knowledge on the topic of methane-reducing feeding strategies, which can be helpful in discussions in this area, among other things. The scientific reviews by Arndt et al [4] (including meta-analysis to quantify the reduction potential of various measures), Beauchemin et al [5] and Hegarty et al [6] on CH_4-reducing strategies, support measures and CH_4 inhibitors (substances that reduce CH_4 formation) form the main basis for this data sheet. Further measures and strategies for reducing CH_4 emissions at farm and management level are described separately in the data sheet "Strategies for methane reduction in dairy farming".

Formation of methane in cattle

The majority of carbohydrates (cellulose, hemicelluloses, starch, fructans, sugar and others) are broken down microbially in the rumen (fermentation). The end products of this microbial degradation are volatile fatty acids (primarily acetic acid, propionic acid, butyric acid) and the gases carbon dioxide (CO_2) and methane (CH_4).

Hydrogen (H_2) is released during microbial carbohydrate degradation. To prevent an excessive accumulation of hydrogen in the rumen, methanogenic archaea use the excess H_2 and CO_2 to produce CH_4 (methanogenesis) and thus ensure the balance of fermentation conditions in the rumen [8].

The volatile fatty acids are absorbed via the rumen wall, transported to the corresponding tissues and represent the main source of energy for ruminants. The gases formed are excreted with the rumen. In the process, the animal also loses a considerable amount of feed energy via the CH_4 (on average between 5 - 7 % of the gross energy consumed) [8].

The proportion of degradation products in the rumen varies depending on the composition and degree of processing of the carbohydrates in the feed. Methane is mainly produced when carbohydrates are broken down to acetic acid, as more hydrogen is released during this degradation process. This is particularly the case with rations rich in cellulose or crude fiber, while rations rich in starch and sugar (cereal and concentrate feed) shift the ratio in favor of propionic acid formation. Hydrogen is consumed during the formation of propionic acid, so that less hydrogen is available for the formation of CH_4 [9].

In addition, the level of feed intake, the fiber and fat content of the ration and the passage rate of the feed influence CH_4 formation: As the feed level increases, the passage rate increases, which simultaneously leads to a decrease in CH_4 output per kg feed intake [8, 10]. However, the relationship between feed intake and CH_4 output is not linear, and the decrease in CH_4 output decreases as the feed level increases [8].

Important key figures for evaluating CH_4 emissions include

CH_4 absolute (**CH_4 abs**): g CH_4 per animal and day

CH_4 yield (**CH_4E**): g CH_4 per kg feed intake

CH_4 intensity (**CH_4I**): g CH_4 per kg energy corrected milk (ECM; **CH_4I_M**) or meat (**CH_4I)** $_F$

CH_4I is becoming increasingly important and is the most important indicator for assessing CH_4 emissions. The aim of CH_4 reduction measures should be to reduce both absolute and product-based emissions while maintaining or increasing animal performance [4]. Sustainable strategies to reduce enteric CH_4 emissions should not have environmental or socio-economic trade-offs or have a negative impact on animal performance [5].

Optimize digestibility and performance from roughage

Mode of action

- Optimization of the output from the **roughage** enables reduction of the concentrate feed while maintaining the same output
- Increase in milk yield from roughage → This is accompanied by an increase in overall performance
- Improvement in the digestibility of roughage → Feed intake and performance increase → CH_4E and CH_4I decrease [5]
- Increase in feed intake: feed passage rate increases → less time in the rumen for microbial degradation, but CH_4abs increases due to higher feed intake and fiber digestibility decreases.
- Reduce grass maturity: increases milk yield presumably due to better digestibility → CH_4I decreases.

Reduction potential

- Reduction of upstream GHG emissions from concentrate feed production [11]
- Higher total output → Number of dairy cows can be reduced → CH_4abs decreases [11].
- Optimization of performance from roughage uses the advantage of the ruminant as a roughage utilizer → essential for closing the carbon cycle.
- Increasing feed intake: effective strategy for reducing product-related CH_4 emissions [4]:
- CH_4I_M : -17 %; $CH\ I_{4F}$: no data available;
- Reduced fiber digestibility may increase CH_4 emissions from farmyard manure (further studies required).
- Reducing grass maturity: effective strategy for reducing product-related CH_4 emissions [4]:
- CH_4I_M : -13 %; $CH\ I_{4F}$: no data available.

Context

- Suitable for stable and pasture systems.
- Improve roughage digestibility of hay and silage through: optimal cutting time [5].
- Grazing systems: Optimize pasture management: adjusted stocking rate, avoid overgrowth to reduce grass maturity [5].
- Observe optimum phenological stages for grazing and forage harvesting (see also data sheet on "Management of meadows and pastures based on temperature sums")
- Combining improved digestibility with other measures → To assess the overall farm GHG balance, animal and lifetime performance, the quantity and composition of farmyard manure, roughage yield and the use of farm inputs must be taken into account [5].
- Young grass: note higher N contents and balance if necessary → can increase N emissions [5].
- Consider optimization options for performance from roughage on an individual farm basis → Include advice Use feed planning and climate tools [11].

Ruminants = roughage utilizers → An optimal roughage supply and quality should always form the basis for all further measures due to the special nutritional status of ruminants.

Ration composition

Mode of action
• Increasing the starch content through higher proportions of maize silage or starch-rich by-products from the food industry: shift in the ratio of volatile fatty acids from acetic to propionic acid → methanogenesis is reduced [5; 9] + lowering the rumen pH → inhibits the activity of fiber-degrading bacteria and protozoa [8].
Reduction potential
• CH_4I_M (per kg ECM) -2 % for every 1 % increase in non-fiber carbohydrates (starch, sugar, pectin), the CH_4 emission per kg ECM decreases by 2 %; maximum reduction of up to 15 % possible [9]. • Reduced activity of fiber-degrading bacteria and protozoa → more undigested fiber in the slurry → higher CH_4 emissions from the slurry possible [8].
Context
• Particularly suitable for stall systems. • Higher starch intake: increased risk of rumen acidosis → Ensure the structural effectiveness of the ration, even with higher maize silage proportions! • Increased competition for land: Consider the role of cattle as grassland utilizers! → Increasing the proportion of maize silage = conflicting objectives with milk production from grass. • Increased use of by-products from the food industry can avoid food competition (compared to the use of concentrated feed). • A maximum of 25 % maize silage in the total ration (per kg dry matter/substance) is advantageous → Higher proportions may require the use of additional (imported) protein sources → Consider possible negative effects on the overall GHG balance/sustainability [13].

Source: LKV BW

Grassland composition

Mode of action

- **Tannin-rich fodder plants**: see Tannin mode of action (page11)
- **Perennial legumes**: lower NDF content than grasses at a comparable physiological stage + some species are rich in tannins and saponins → Increase in the nutrient content of the ration → Higher performance → Reduction of CH_4I
- **High-sugar ryegrass varieties** (*Lolium perenne L.)*: high concentration of water-soluble carbohydrates and lower protein content → reduces acetic acid:propionic acid ratio [5].

Reduction potential

- **Tannin-rich forage crops** as an effective strategy for reducing absolute CH_4 emissions [4]:
- $CH\ I_{4M}$: -18 % / $CH\ I_{4F}$: no data available;
- CH_4abs: -12 %;
- CH_4E: -10 %;
- Reduced fiber digestibility: -7 % → may increase CH_4 emissions from the manure.
- Reduction potential varies depending on the species: *Sericea lespedeza* (*Lespedeza cuneata)* and *Lotus (Lotus corniculatus* and *Lotus pedunculatus)* are particularly effective without negatively affecting feed intake.
- **Perennial legumes**: Reduction potential difficult to quantify and dependent on proportion in the ration, feed intake and quality, phenological plant stage, digestibility.
- **High-sugar grasses**: CH_4E: -0.311 g/kg feed intake per 10 g/kg DM increase in water-soluble carbohydrates [5].
- Reduction potential reduced by preservation as hay or silage [15].

Context

- Strategy suitable for grazing system.
- **Tannin-rich forage plants** may be less palatable → Reduction in feed intake [4] and digestibility [14] → Ration proportion thus limited.
- Tannins can bind to proteins and reduce degradability in the rumen → see page 11.
- **Perennial legumes** can make a positive contribution to N supply and reduce the use of purchased (imported) protein sources; fix N in the soil and can promote carbon storage in the soil → complex interactions overall [5].
- **High sugar grasses**: further research needed on reduction potential, crop yield and animal performance in different production systems [5].

Use of feed fats and oilseeds

Mode of action

- Medium-chain, polyunsaturated fatty acids from vegetable oils (sunflower, linseed and rapeseed oil).
- Toxic for methanogens and protozoa; promotes propionate formation + biohydrogenation (accumulation of H_2) of unsaturated fatty acids consumes H_2 , which is then no longer available for CH_4 formation [5].
- The proportion of non-fermentable but highly digestible energy in the ration increases, while feed intake and fiber digestibility decrease [4].
- Effect depends, among other things, on the fatty acid pattern of the basic ration, basic to concentrate feed ratio, processing, fat source and amount used [16].

Reduction potential

- **oils and fats** as an effective strategy for reducing absolute CH4 emissions [4]:
- CH I_{4M} : -12 % / CH I_{4F} : -22 %;
- CH_4abs: -19 %;
- CH_4E: -15 %;
- Reduced fiber digestibility: -4 % → may increase CH_4 emissions from the manure;
- Feed intake: -6 %.
- No influence on milk/fattening performance due to high energy content of fats and oils.
- **oilseeds** (crushed/crushed) as an effective strategy for reducing absolute CH_4 emissions [4]:
- CH I_{4M} : -12 % / CH I_{4F} : no effect;
- CH_4abs: -20 %;
- CH_4E: -14 %;
- Reduced fiber digestibility: -8 % → may increase CH4 emissions from the manure.
- Negative effect on fattening performance → Use only recommended in milk production.
- Fat supplementation: decrease in CH_4E of approx. 4 % per 10 g/kg DM of additional fat, depending on the source [5].
- There is evidence of a long-term methanogenic effect [5].

Context

- Fat content of the ration max. 60 g/kg DM (if protected fats are used, otherwise 40 g/kg DM) [8] → otherwise adverse effects on rumen fermentation, digestion, fiber digestibility and performance are possible [5].
- Long-chain polyunsaturated fatty acids can improve the fatty acid profile of milk and meat for human nutrition.
- The use of enteric fermentation is sometimes expensive; at the same time, cultivation, processing and transportation increase GHG emissions from feed production [16; 17], but enteric fermentation has a greater impact on GHG emissions [4].
- Competition for food and land is increasing due to the cultivation of oilseeds.

3-Nitrooxypropanol (3-NOP)

Mode of action

- Blocks the activity of the key enzyme (methyl-coenzyme M reductase) in the final step of methanogenesis in archaea [5].
- Only low doses (60 to 200 mg/kg DM) necessary, but mode of action of 3-NOP is limited in time (max. 6 h) → Continuous intake of the feed additive via the feed required [6].

Reduction potential

- Very high reduction potential [6][1].
- The use of CH_4 -inhibiting feed additives (especially 3-NOP) is an effective strategy for reducing absolute CH_4 emissions [4].
- CH_4abs: about -30 % (at typical intake levels in cattle fattening (144± 82.3 mg/kg DM) and dairy cow husbandry (81 ± 41.2 mg/kg DM)) [5].
- Greater reduction potential for dairy cows than for beef cattle [5].
- Reduction potential is dose-dependent [5] and may be breed-specific [18].
- Reduction efficiency decreases with increasing NDF content of the ration [5].

Context

- Currently the most promising and effective feed additive with no negative effects on animal performance.
- In the EU and Switzerland, 3-NOP has been approved as a feed additive since 2022 (Bovaer®, marketed by DSM).
- Effectiveness has been proven in > 20 laboratory and feeding trials, but so far only in the context of TMR rations → Transferability of the results to systems with a high proportion of pasture is currently being investigated.
- Use of 3-NOP increases the milk fat content [4].

[1] CH_4 reduction potential: >25 %: very high; >15 - 25 %: high; >5 - 15 %: medium; ≤5 %: low [6].

Red seaweed

Mode of action
• Accumulation of bromoform (= bioactive substance) in **red marine algae** (e.g. *Asparagopsis taxiformis* and *Asparagopsis armata*) → indirectly inhibits the last step of methanogenesis through a reaction with vitamin B_{12} [5].
Reduction potential
• Very high reduction potential [6]. • Decrease CH_4abs between 9 and 98 % [5]. • Reduction efficiency depends on the bromoform content of the algae and the ration composition (better effect in concentrate-based rations) [5]. • There are concerns that *Asparagopsis* could lose its effect in the long term [5].
Context
• Possible dose-dependent reduction in feed intake, simultaneous positive effects on animal performance possible. • Further studies are necessary, especially for feeding partially mixed rations and for pasture-based systems [19]. • Bromoform is classified as possibly carcinogenic → No residues in milk or meat at use levels of <5 g/kg DM detected so far [5]. • High iodine content also limits the quantities used [4]. • To assess the overall GHG balance: consideration of upstream emissions (production, harvesting, processing, storage and transportation) [5].

Source: Wikipedia/Jean-Pascal Quod/CC BY-SA 3.0

Tannins (tannins)

Mode of action
• **Tannins** (= polyphenolic compounds; subdivision into hydrolyzable and condensed tannins): direct inhibition of methanogens and indirectly by reducing the number of protozoa that live in symbiosis with methaone genes [5].
Reduction potential
• Low reduction potential [6].   • **Tannins**: linear decrease in CH_4E of 3.53 % per addition of 10 g/kg DM. with a simultaneous decrease in the digestibility of organic matter [5].   • CH_4 -reduction may also be due to a decrease in feed intake and nutrient digestibility → Impairment of performance possible [5].   • Reduction potential depends on the source and class of tannins, the molecular weight of the tannins and the rumen microbiome [5].
Context
• Effects on feed intake, digestibility, animal performance and health unclear [5].   • Hydrolyzable tannins appear to be more effective, but toxic metabolites are formed during degradation in the intestine → Max. amount of hydrolyzable tannins used: 30 g/kg DM [5].   • Tannins can bind proteins → Improvement of N efficiency + reduction of N losses via urine as well as ammonia and nitrous oxide emissions [20].   • Use of tannin-containing plants and legumes → Conceivable use in pasture-based production systems.

Source: https://www.pflanzen-vielfalt.net/

Examples of tannin-containing forage plants: Sainfoin, horned clover

Essential oils

Mode of action
• **Essential oils** = complex volatile secondary plant substances that are responsible for the typical smell and aroma. • In extracted and concentrated or synthetically produced form, they can exert antimicrobial activities against bacteria and fungi [5].
Reduction potential
• Low reduction potential [6]. • Many essential oils show methane-inhibiting properties *in vitro* when used in high quantities → cannot be converted *in vivo*. • Long-term effect and possible adaptation of the rumen microbes to these substances: unknown. • Decrease in CH_4 emissions with 1 g/day of agolin (mixture of various essential oils, Agolin Ruminant; Agolin SA) [21]: • CH_4abs: -9 %; • CH_4E: -13 %; • CH_4I_M : -10 %.
Context
• >3000 essential oils → extensive need for research on dosage, combination and use under *in vivo* conditions [5]. • Caution is advised with high application quantities, but only a low risk of poisoning with recommended application quantities [5]. • Agolin can improve milk yield (+4 %) and feed efficiency (+4 %) [21]. • Mechanism of action of agolin not yet clarified and study situation limited [21].

Directly fed microorganisms

Mode of action
• Alteration of rumen fermentation by living microorganisms: divert existing H_2 into alternative pathways → can no longer be used for methanogenesis [5]. • Use of bacteria that inhibit the growth of methanogens [5].
Reduction potential
• Low reduction potential [6. • Variable effects on CH_4 emissions, but sometimes improvement in milk yield → reduction in CH_4I_M possible [5]. • CH_4 -reducing effects only confirmed in feeding trials in exceptional cases [5] (due to low efficacy, no repeatability of the studies, among other things).
Context
• It is unclear whether the addition of microorganisms for CH_4 -inhibition may have adverse effects on animal performance → Further studies are needed on the influence on digestibility and manure composition as well as dosage [5].

Source: LKV BW

Summary: opportunities and challenges

- A **holistic approach** is required to achieve sustainable milk and meat production. It is important to move away from the pure consideration of CH_4 emissions and focus on the entire GHG balance.

- It should be borne in mind that one strategy/measure alone is not effective, but that a **combination of different measures**, both at feeding and farm level, should be sought in order to efficiently exploit the reduction potential.

- The expected CH_4 reduction must always be considered **both in absolute terms** (per animal and day) **and in terms of intensity** (per unit of animal product). Some strategies are likely to lead to an immediate reduction, for example the use of special feed additives. Others cause more gradual effects over time, e.g. the optimization of milk yield from roughage, which reduces product-related emissions, but a reduction in the number of animals is also conceivable.

- The impact of CH_4 mitigation strategies on emissions of **other greenhouse gases** (both upstream and downstream) must be assessed. Upstream changes include, for example, the direct and indirect release of carbon dioxide (CO_2) and nitrous oxide (N_2 O) during plant growth and the production of specific feedstuffs, certain feed additives or other products. Changes can also affect, for example, CH_4 and N_2 O emissions from manure. In addition, changes in plant production and pasture management may have an impact on carbon sequestration in the soil.

- The impact of CH_4 mitigation strategies on **meat and milk production and feed efficiency** must also be assessed.

- **Long-term studies** on the use of CH_4 -inhibiting feed additives are **often not available**. There is a need for further research into whether and to what extent the rumen microbiome adapts over the duration of administration and the reduction potential is therefore limited.

- **Special case of organic farms**: Feeding situation: lots of grassland, little maize and additional purchases, many additives are not permitted → Consideration of CH_4 excretion probably worse here in terms of feeding, the CH_4 balance for the farm as a whole may also be worse due to a lower milk yield. But the GHG balance for the farm as a whole is probably better due to fewer CO_2 equivalents from the upstream sector, such as additional purchases, etc.

- Furthermore, concerns regarding the **potential toxicity** for animals, humans and possibly residues in animal products and in relation to the environment must be taken into account.

- Potential obstacles to the introduction of a reduction strategy: very different depending on the **company, region and country**. These include biological (accessibility, safety), economic (costs, lack of incentives), legal, environmental and social aspects (resistance to change, technical support, consumer acceptance).

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