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REVIEW ON THE INFLUENCE OF DAIRY CATTLE HEALTH EFFECTS ON GREENHOUSE GAS EMISSIONS

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Abstract

Climate changes represent a major threat to society, due to its wide impact on ecosystems, economy, human and animal health. The aim of this review was to evaluate the influence of dairy cattle health and their implications on greenhouse gas (GHG) emissions intensity. The main influencing factors concerning the GHG intensity of dairy cattle that are discussed in this review article are nutrition, animal productivity, longevity and fertility, in relationship with animal health. Data showed that high levels of animal health not only led to increased productivity performances, however, it translates into a significant decrease of GHG emissions. Moreover, metabolic disorders during the transition period of lactating cows represent a critical risk for cows mortality, productivity and economical losses, and higher GHG emissions/kilogram/milk. Overall, the reductions in GHG emissions intensity could be achieved through the implementation of proper animal health management programs at individual farm level.

Key words: *animal nutrition, dairy cattle, greenhouse gas emissions, health, metabolic disorders.*

INTRODUCTION

Climate changes represent a major threat to society, due to its wide impact on ecosystems, economy, human and animal health.

It was proved that the livestock emissions contribute to the overall global warming and climate changes (Scoones, 2022; Grossi et al., 2019).

With an expected increase in milk consumption, and potential new policies to reduce greenhouse gas (GHG) emissions from agriculture, producing efficiently and reducing GHG from dairy cattle sector, has gained research interest (Mostert et al., 2018a).

Increased animal production efficiency can be achieved by improving animal health status, extending the productive life of animals, and improving reproduction performances.

Poor livestock health and welfare are associated with behavioural and metabolic changes, which can lead to an increase of GHG (Grossi et al., 2019), unhealthy animals tending to have a lower milk yield, fertility and longevity, resulting in higher emissions/unit of animal product (Wei et al., 2021).

The most prevalent dairy cattle health issues include mastitis, lameness, reproductive disorders, clinical and subclinical ketosis (Raboisson et al., 2015; McArt et al., 2012; Bruijnis et al., 2010; Duffield et al., 2009), such diseases having a significant economic impact and the potential to increase GHG/unit of output (Naranjo et al., 2020).

The potential reductions of GHG emissions in the dairy sector (kg CO_2 eq/kg product) and thus the improvement of food security, can be reached by disease prevention, and such approaches should be of considerable interest to all stakeholders involved in the dairy chain.

It was estimated that a rise of 5% diseases prevalence leads to a GHG/kg of milk increase of 1.1%, while a rise of 45% in the FMD (foot and mouth disease) disease prevalence, leads to a 10.0% increase in GHG/kg milk (Capper, 2023).

There is a considerable body of literature and evidence linking improvements in dairy cattle productivity with reduced feed resources per unit of milk produced, and therefore an improvement of the overall environmental sustainability of the sector (Capper & Cady, 2019; Caro et al., 2014; Capper & Bauman, 2013; Bell et al., 2013; Wall et al., 2012; Zehetmeier et al., 2011; Capper & Cady, 2010; Capper et al., 2008; Casey & Holden, 2005).

A method that assesses the environmental impact of a product is Life Cycle Assessment

(LCA), which takes into account the entire life cycle in the animal production chain (Wolf et al., 2017; Baumann & Tillmann, 2004).

Primarily, LCA has been used for dairy cattle to estimate the impact of feeding strategies (Van Middelaar et al., 2014a), improved fertility and increased longevity (Bell et al., 2011) or milk yields, and to a lesser extent it was used to evaluate the impact of diseases prevalence on GHG emissions (Mostert et al., 2018).

It was shown that by reducing disease prevalence, GHG can be reduced, leading to an increase of the overall dairy farm's incomes (Liang et al., 2017; Van Soest et al., 2016), while improving the welfare of cattle.

This review paper aims to evaluate the influence of dairy cattle health and their implications on greenhouse gas emissions intensity.

MATERIALS AND METHODS

Bibliographic data from national research journals, international databases (Scopus, PubMed, ScienceDirect), personal research were used to present the scientific information from this paper.

RESULTS AND DISCUSSIONS

Livestock and GHG emissions at the European Union level

The most important greenhouse gas (GHG) emissions in ruminants farms (bovines and small ruminants) are carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). In 2021, official data showed that 10.7% of the total GHG emissions in the EU were produced by the agricultural sector (Eurostat, 2023). It is estimated that during the last 30 years, the EU agricultural sector reduced its GHG emissions by 22%, which corresponds to 106 million tonnes of CO_2 equivalent (CO_2eq), compared to 1990 as a reference year. Moreover, emissions resulted from ruminants enteric fermentation processes were reduced by 23%, the equivalent of 54 million tonnes of CO_2 in 2021, when compared with year 1990 (Eurostat, 2023).

The official reports show that the largest share of GHG emissions due to enteric fermentation come from the digestive system of cattle (85%) With cattle produced emissions decreasing by 22%, 45 million tons of CO_2 equivalent, in the last three decades.

The reduction in GHG emissions being attributed mainly to the decrease of the total number of bovines raised in the EU, with an abrupt decrease of bovine numbers of 11% (9 million heads) during the last 20 years alone (Figure 1).

As a result of better manure management practices in the EU during the last three decades, such as storing platforms designs and regulations on agricultural lands administration, the GHG emissions from cattle manure were reduced by 19%, which represents a 7 million tons of CO_2 equivalent (Eurostat, 2023).

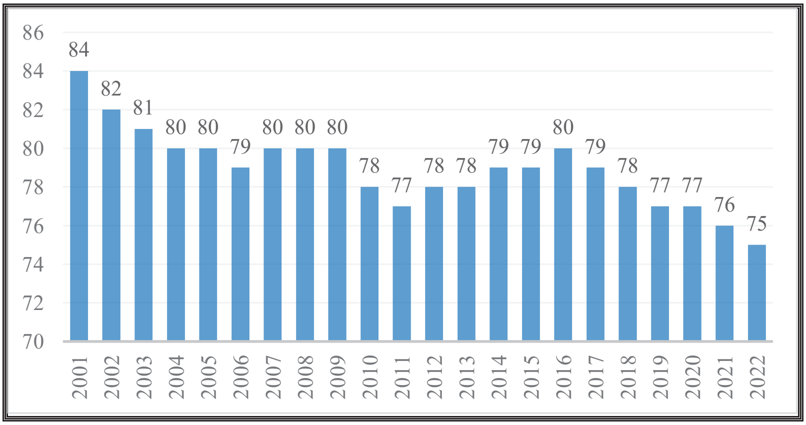

Figure 1. EU bovine population between 2001-2022 (million heads), Source: Eurostat, 2023

Dairy cattle nutrition and its impact on GHG emissions

It was outlined that efficient milk production and the reduction in the environmental impact throughout new and adapted feeding strategies are possible and necessary (Van Zanten et al., 2014).

Milk production losses in the dairy industry are caused mainly by poor nutrition, management imbalances and diseases. Health issues in dairy cattle farms increase the labour for farmers, veterinary treatment costs, reduce feed efficiency, and therefore, reduce the income of the dairy cattle farms.

Recent studies showed that an increase in feed intake, which leads to a higher energy and nutrient intake, has the potential to improve the ratio between energy available for milk yield and the one needed for maintenance functions, such as the immune system and metabolism.

In a study published by Von Soosten et al. (2020), it was showed that the energy intake for maintenance decreased for dairy cows which consumed 10 kg dry matter/day from 54% to 20% of their total energy intake, when cows consumed 25 kg of dry matter/day, of the same feed. The study outlining that although the CH_4 emission/animal/day increased with the dry matter intake, however, the emission per kilogram of milk produced decreased.

Similarly, Hristov et al. (2013) showed that cattle enteric CH_4 emissions can be reduced by several nutritional approaches, such as improving forage quality, increasing the amount of concentrates over roughage, or throughout the inclusion of dietary lipids in the adult cattle diets.

It is worth pointing out that different nutritional strategies to reduce GHG emissions in the dairy cattle sector might negatively impact GHG emissions and processes along the production chain, e.g. higher concentrates level necessitate soybean meal imports from outside of the EU (e.g. South American countries), which leads to emissions caused by the production and transport.

Moreover, a change in the diet of cattle, might reduce enteric CH_4 emissions, and this to cause a chain reduction of other GHG emissions, such as CO_2 and N_2O (Van Middelaar et al., 2013).

Nutritional plane persistence was proven to play a role in GHG emissions of cattle, with the work of Boichard & Brochard (2012) showing that feed management practices which had led to maintaining the herd's milk yield at a constant level, while avoiding milk production fluctuations, have led to a decrease in the GHG emissions.

In lactating dairy cattle, fatty acid (FA) profiles can be used as indicators for milk quality (Lingen et al., 2014; Dijkstra et al., 2011) and the diets with high concentrations of polyunsaturated fatty acids (PUFA) had as effects a decrease of the methane production. Similarly, Chilliard et al. (2009) reported a high positive correlation between saturated FA and methane production.

Regarding nutritional strategies, based on available data (Popa et al., 2022; Popa et al., 2021), it can be assumed that different feeding strategies can have as outcome a reduction in GHG emissions of 9-32 kg CO_2 eq/t of fat and protein corrected milk (FPCM), estimated by Van Middelaar et al. (2014b).

Roque et al. (2019) showed that adding 0.5-1% seaweed in the dairy cow's diet led to a 27-67% reduction in methane intensity per kg of milk produced.

All individual studies used in the meta-analysis by Almeida et al. (2021) noted the efficacy of 3-nitrooxypropanol (3-NOP) in reducing enteric CH_4 emissions. Supplementation of the diets with 3-NOP reduced ruminant CH_4 emission by 23.3% compared to the control diets, based on different studies, methane reduction ranged from 6.5% to 38.0% in lactating dairy cattle.

Cattle productivity and GHG emissions

Generally, higher milk yields result in higher emissions per animal, while lowering emissions per kg of FPCM. In their study, Zehetmeier et al. (2012) showed that GHG emissions per kg of milk decrease with the increase in milk yields from 6000 kg/lactation to 10.000 kg/lactation, from 1.06 kg CO_2 eq/kg of milk produced to 0.89 kg CO_2 eq/kg of milk produced. Similar reports by Van Middelaar et al. (2014a) showed that increasing milk yield with 698 kg/year/cow has lead to a reduction of 27 kg CO_2 eq/t of FPCM. These values correlated favourably with Bannink et al. (2011), which found that increasing the daily milk yield per cow from 17.2 kg to 22.9 kg has

decreased the enteric CH_4 emissions per unit of milk by 13%.
Alongside milk yields, the animal live weights were shown to influence GHG emissions. Niemann et al. (2011) reported that dairy cow with 650 kg live weights, 25 kg dry matter intake/day and milk yields of 40 kg/day, emitted 12 CO_2 eq/t FPCM vs. cows with 650 kg live weights, 12 kg of dry matter intake/day and having 10 kg milk/day, which emitted 30 CO_2 eq/t FPCM.
Regarding milk yields and GHG emissions, there is a growing body of studies showing that an increase in productivity, leads to a reduction of the overall emissions per kg of milk, thus throughout a better animal selection and improved herd management, GHG emissions could be indirectly reduced, synergically.

Longevity, fertility and GHG emissions

Prolonging dairy cattle productive life is regarded as one of the main alternatives to contribute to a more sustainable dairy production sector.
The longevity of dairy cows has gained increasing attention in recent years, largely due to the environmental (Bergea et al., 2016) and economic implications (Dallago et al., 2021) associated with a short longevity of 2.2-2.4 lactations.
Increasing the length of the productive life (LPL) in dairy cattle could be considered as an option to mitigate GHG emissions, as this reduces GHG emissions resulted from the rearing of replacement heifers (Bell et al., 2015), with implications in the profitability of milk production (De Vries, 2017).
Moreover, the milk production increases in dairy cows up to the 3^{rd}-4^{th} lactations, when it reaches the maximum yields, and starting the 5^{th} or 6^{th} lactations, it starts to decrease. As a result, culling dairy cattle during the first two lactations represents a significant loss, due to the overall physiological underproduction of primiparous and secundiparous cows.
Several studies, such as ones published by Humer et al. (2018) and Bell et al. (2011), demonstrated that poor fertility of dairy cows leads to increases in the GHG emissions.
One of the most noteworthy estimates regarding relationships between fertility and GHG was that of Garnsworthy (2004), which determined that improvements in the fertility of cows could reduce CH_4 emissions by 24%, throughout reducing the number of replacement heifers needed in the herd. The same author showing that in dairy farms, the GHG emissions decrease with the number of artificial inseminations (AIs) per gestations confirmed, from 0.926 kg CO_2 eq/kg of FPCM at 4 AIs/gestation to 0.915 kg CO_2 eq/kg of FPCM at 6 AIs/gestation.
Recently, Han (2023) showed that although lower subfertility culling reasons has the potential to extend dairy cattle longevity, the increase in the number of AI services could benefit more benefit more the economic net return, while mitigating GHG emissions as well. Similarly, Grandl et al. (2019) showed that increasing the length of the productive life of dairy cows reduces the climate impact per animal and improves profitability.
Authors estimating that the contribution of breeding replacement costs decreased continuously from 38% to 9% of the total costs, for cows when the length of productive life increased from 1 year to 7 years.
Furthermore, Van Middelaar et al. (2014a) reported that increasing longevity with 270 days/cow has led to a reduction of 23 kg CO_2 eq/t FPCM.
From a different perspective, Sekyere et al. (2023) found an association between farm infrastructure and farm investments, which according to the authors is strongly and positively correlated with cow longevity in Swedish dairy herds.
It is generally accepted within the dairy industry that higher dairy herd longevity is associated with higher milk yields and longer calving intervals, while prolonging age at first calving for primiparous cows reduces the productive longevity of the herd.
Grandl et al. (2019) reported that a large number of cows are removed from the herd early in lactation mainly because of metabolic health reasons.
Based on findings of recent studies, it can be affirmed that cows with an increased longevity produce less methane per kg of milk (Grandl et al., 2018), which in return improves the overall environmental sustainability (Overton & Dhuyvetter, 2020) and is indicative of good animal welfare (Barkema et al., 2015).

Metabolic disease and GHG emissions

Globally, Grace et al. (2015) estimated that livestock diseases are reducing livestock productivity by 25%. It was demonstrated that for dairy cattle, the transition period represents the time in which the risk of developing metabolic diseases is the highest. This risk during the transition from late gestation to early lactation is caused mainly by the significant metabolic and hormonal changes that occur (Dzermeikaite et al., 2024). Poor nutritional status during the transition period leads to higher incidences of metabolic diseases such as ketosis, mastitis, hypocalcaemia, retained placenta, metritis and displaced abomasum. Furthermore, subclinical ketosis (SCK), increases the risk of developing other diseases such as clinical ketosis, mastitis, metritis, displaced abomasum and lameness, all while increasing GHG emissions per kg of milk, reducing thus the production efficiency in dairy cattle herds. The implications of SCK on GHG emissions was highlighted in a recent study by Mostert et al. (2018a), which showed that the GHG emissions increased on average by 20.9 kg CO_2 eq/t FPCM per each case of SCK per cow, related to reduced milk production, discarded milk, prolonged calving interval, and removal (Table 1).

Authors reported that the increase in emissions was caused indirectly by resulting prolonged calving intervals (31%), discarded milk due to antibiotics use (30%), reduced milk production (19%), and the culling of cows (20%). Moreover, for cows which developed SCK exclusively, the GHG emissions increased by 7.9 kg CO_2 eq/t FPCM, whereas GHG emissions for cows that were culled increased by 188.2 kg CO_2 eq/t FPCM and for cows that died on-farm, the GHG emissions increased by 463.0 kg CO_2 eq/t FPCM. In a study following the effects of the udder health on GHG emissions, Hospido and Sonesson (2005) found that by reducing the subclinical mastitis incidence from 33% to 15%, and the incidence for the clinical mastitis from 25% to 18%, the GHG emissions could be decreased by 2.5%.

Similarly, in another study focused on de clinical mastitis (CM), it was shown that GHG emissions increased on average by 58 kg CO_2 eq/t FPCM per each case of clinical mastitis within the herd, related to reduced milk production, discarded milk, prolonged calving interval, removal, and avoided burden (Mostert et al., 2019).

Authors attributing the increase to causes such as animal culling (39%), discarded milk due to antibiotics treatment (38%), reduction of the milk production (17%) and to prolonged calving intervals (6%).

Same authors found that the increases in GHG emissions per case of CM varied based on parity, from 75 kg CO_2 eq/t FPCM in primiparous cows, to 34 kg CO_2 eq/t FPCM in cows in their 5^{th} parity.

Additionally, similar findings were reported by Ozkan Gulzari et al. (2015), who found a 2% increase in GHG emission/kilogram of milk produced for subclinical mastitis cases.

In another similar study Ozkan Gulzari et al. (2018), showed the potential to reduce GHG emission intensity in dairy cattle farms by up to 3.7% throughout a reduction in the somatic cell count from 800.000 cells/mL to 50.000 cells/mL.

Next to metabolic diseases, foot lesions (digital dermatitis, white line disease and sole ulcer) were shown to increase GHG emissions in dairy cattle, on average by 14 kg CO_2 eq/t FPCM, related to prolonged calving interval, culling, and avoided burden (Mostert et al., 2018b).

The authors found a similar trend in foot lesions as in the case of clinical mastitis, with the impact on GHG emissions being lower for cows with higher parities, decreasing emissions from 17 kg CO_2 eq/t FPCM in 1^{st} parity cows to 7 kg CO_2 eq/t FPCM in 5^{th} parity multiparous cows.

Chen et al. (2016) estimated that generally lameness increases GHG emissions per kg of milk produced by 0.7% to 7.8%.

There is a growing body of literature and evidences showing that GHG emissions at the dairy herds level are significantly impacted by the prevalence of diseases, and some of the diseases act synergistically.

As a results, a well-managed transition period for dairy cows can lead to a reduction in the GHG emissions, while improving the overall health and welfare levels during this critical time.

Table 1. Impact of the diseases on GHG emission in dairy cows (source: Mostert et al., 2018a; 2018b; 2019)

Disease	GHG emissions (kg CO_2 eq/t FPCM*)
Subclinical ketosis and confounding effects (average/case)	+20.9
Subclinical ketosis (alone)	+7.9
Subclinical ketosis + mastitis	+63.4
Subclinical ketosis + metritis	+33.8
Subclinical ketosis + displaced abomasum	+55.8
Subclinical ketosis + lameness	+31.6
Clinical ketosis	+27
Subclinical ketosis (parity 1)	+15.1
Subclinical ketosis (parity 5)	+26.6
Subclinical ketosis which has lead to culling of the cow	+188.2
Subclinical ketosis which has lead to death of the cow	+463.0
Clinical mastitis and confounding effects (average/case)	+58
Clinical mastitis (one case/lactation)	+48
Clinical mastitis (two cases/lactation)	+69
Clinical mastitis (three cases/lactation)	+92
Clinical mastitis (parity1)	+75
Clinical mastitis (parity 5)	+34
Clinical mastitis (first case/lactation) – type of pathogens: Gram -	+65
Clinical mastitis (first case/lactation) – type of pathogens: Gram +	+54
Clinical mastitis which has lead to culling of the cow	+115
Clinical mastitis which has lead to death of the cow	+322
Foot lesions and confounding effects (average/case)	+14
Foot lesions (parity 1)	+17
Foot lesions (parity 5)	+7
Digital dermatitis	+4
White line disease	+39
White line disease (parity 1)	+59
White line disease (parity 5)	+6
Sole ulcer	+33
Sole ulcer (parity 1)	+60
Sole ulcer (parity 5)	+11

*CO_2 eq/t FPCM = CO_2 equivalents/ton of fat-and-protein-corrected milk (FPCM).

CONCLUSIONS

Preventing diseases could represent an effective strategy for farmers to reduce GHG emissions, and can contribute to the sustainable development of the dairy sector.

This review showcased existent research results on reducing GHG emissions throughout nutritional, health, management and selection approaches, which can synergistically be used to reduce GHG emissions per unit of produced milk, mitigating the impacts of livestock production on the environment.

The evidence from the reviewed literature strongly suggests that GHG emissions could be reduced by over 20% through the use of feed additives such as methane blockers, while a reduction of the most prevalent diseases (ketosis, mastitis and lameness) could contribute to a further reduction of 2-5%. Overall, the reductions in GHG emissions intensity could be achieved through the implementation of proper animal health management programs at dairy cattle farm level.

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