Dairy Cow Health and Greenhouse Gas Emission Intensity

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Abstract: The purpose of this review is to identify the main influencing factors related to dairy cow health as it impacts the intensity of greenhouse gas emissions considering known data presented in the literature. For this study, we define the emission intensity as CO2 equivalents per kilogram of milk. In dairy cows, a high dry matter (DM) intake (25 kg/d) leads to an higher absolute methane emission compared to a lower DM intake (10 kg/d). However, the emission intensity is decreased at a high performance level. The emissions caused by DM intake to cover the energy requirement for maintenance are distributed over a higher milk yield. Therefore, the emission intensity per kilogram of product is decreased for high-yielding animals with a high DM intake. Apart from that, animal diseases as well as poor environmental or nutritional conditions are responsible for a decreased DM intake and a compromised performance. As a result, animal diseases not only mean reduced productivity, but also increased emission intensity. The productive life-span of a dairy cow is closely related to animal health, and the impact on emission intensity is enormous. A model calculation shows that cows with five to eight lactations could have a reduced emission intensity of up to 40% compared to animals that have left the herd after their first lactation. This supports the general efforts to increase longevity of dairy cows by an improved health management including all measures to prevent diseases.

Keywords: dairy cows; animal health; greenhouse gas emissions; emission intensity; methane

1. Background

The world population is projected to reach between 9 and 10 billion people in 2050. Further trade globalization, increased urbanization, and expected growth in global affluence will lead to a substantial increase in the consumption of foods of animal origin such as meat, dairy products, eggs, and fish [1–3]. According to the Committee on Considerations for the Future of Animal Science Research [4], the following three assumptions characterize the basic requirements for future developing conditions:

1. Global consumption of animal protein will continue to increase because of population growth and taking into account per capita consumption of animal protein in many countries.

2. Restricted resources (e.g., water, land, energy, capital) and environmental changes, including climate change, will drive complex agricultural decisions with impacts on research needs.

3. Current and foreseeable rapid advances in basic biological sciences provide an unparalleled opportunity to maximize the yield of investments in animal science research and development.

Food, and especially protein of animal origin can be considered the main objective of animal husbandry, apart from other performances (power, fertilizer, skins, bones, sport, entertainment, etc.). On the one side, products of animal origin contribute substantially to meet human requirements

of amino acids, minerals, and vitamins [5–9], and they have an important enjoyment value. For a better comparison of animal yields, Table 1 shows the yields of edible protein depending on animal species/production categories and performance of animals.

Table 1. Effects of animal species, production categories, and performance on yields of edible protein per animal or per kilogram body weight (BW) and day [10].

Protein Source	Body Weight (kg)	Performance	Edible Fraction (% of Product or of Body Mass)	Protein in Edible Fraction (g/kg)	Edible Protein (g/d)	Edible Protein (g/kg of BW)
		Milk (kg/d)				
Dairy cow	650	10	95	34	323	0.7
		20			646	1.0
		40			1292	2.0
Dairy goat	60	2	95	36	68	1.2
		5			170	2.8
		Body weight gain (g/d)				
Beef cattle	350	500	50	190	48	0.14
		1000			95	0.27
		1500			143	0.41
Growing/Fattening pig	80	500	60	150	45	0.56
		700			63	0.8
		1000			90	1.1
Broiler chicken	1.5	40	60	200	4.8	3.2
		60			7.2	4.8
		80			9.6	6.4
		Laying performance (%)				
Laying hens	1.8	50	95	120	3.4	1.9
		70			4.8	2.7
		90			6.2	3.4

On the other side, animal production also needs to use some limited resources, such as arable land, water, and energy. It also causes emissions such as greenhouse gases (GHGs; e.g., carbon dioxide, CO_2; methane, CH_4; nitrous oxide, N_2O), as well as nitrogen leaching and phosphorous losses with potential freshwater environmental impacts. At the Mauna Loa Observatory in Hawaii, for example, CO_2 levels in the atmosphere increased from about 284 mg/kg in 1832 to 410 ppm in January 2019 [11]. A further increase is expected depending on how countries implement targets for the reduction of their greenhouse gas emissions, and consequently, the global mean temperature will probably be between 2 and 5 °C warmer at the end of the present century [12], with some further negative impacts. These are the reasons to look for all conceivable possibilities to reduce those GHG emissions that are of anthropogenic origin.

High consumption of food from ruminants and high meat consumption in general are in the focus of public criticism because of the resource inputs they require and the high emissions they produce [13–16]. Both are considered major drivers of greenhouse gas emissions from agriculture [16].

Food competition between humans and animals may also be considered a main challenge for both human and animal nutrition. Therefore, a reduction of the amount of human-edible feed in animal diets is also a key factor in view of more sustainable animal feeding systems [17–19]. The efficient and sustainable production of edible protein from ruminants means a low input of feed or rather limited non-renewable resources, such as fuel from fossil sources, water, arable land, and some minerals (such as P) in combination with low emissions [20].

Carbon footprints (CFs) per unit product are frequently calculated to evaluate the GHG loadings of various products considering the global warming potential of different GHGs (CO_2: 1; CH_4: about 23; N_2O: about 296; [21]). In recent years, many papers were published and reviewed investigating the

influence of animal species or category, different protein sources, as well as animal yields and other factors on the inputs of limited resources and emissions [16,22–24]. The authors agree that animal species or category, animal performance, and some other factors may influence the emissions per animal and day, per kilogram of product, or per kilogram of edible protein (Table 2). However, the studies did not pay much attention to the interaction between animal diseases and GHG emissions [25,26].

It is well known that large amounts of CH_4 are produced in the digestive tract of ruminants, and that methane is a highly effective greenhouse gas. However, by and large, also in more recent papers no attention has been paid to consider animal health, animal diseases, or animal losses with regard to a more efficient production of food of animal origin [27,28]. Hristov [29] was one of the first authors who considered animal health and mortality important factors concerning productivity of animals and their implications on GHG emissions. Grace et al. [30] estimated that livestock diseases reduced productivity globally by 25%. Animal health can also be considered a very important topic for a more efficient conversion of feed into food of animal origin and low GHG emissions per product [31]. In order to be able to compare the emission intensity (GHG emitted per kilogram of product) between the animal species, the emission intensity should be described as CO_2eq per kg of edible protein (Table 2). The high ranges of CF (Table 2) rest on many uncertainties, including diseases and mortality. Furthermore, different authors also use different measurements and methods.

Table 2. Ranges of the carbon footprints of food and protein of animal origin, summarized by Nijdam et al. [32].

Protein Source	Studies	kg $CO_{2\text{-eq}}$/kg Product	kg $CO_{2\text{-eq}}$/kg Protein
Cow milk	14	1–2	28–43
Beef, intensive systems	11	9–42	45–210
Meadow, suckler herds	8	23–52	114–250
Extensive pastoral systems	4	12–129	58–643
Mutton and lamb	5	10–150	51–750
Pork	11	4–11	20–55
Poultry meat	5	2–6	10–30
Eggs	5	2–6	15–42
Seafood from fisheries	18	1–86	4–540
Seafood from agriculture	11	3–15	4–75

The ruminants´ values per kilogram of body protein are much higher and mirror a higher range compared to milk protein and proteins from eggs and bodies of non-ruminants.

Low animal yields, poor fertility, and high animal losses cause livestock producers to manage more animals and keep more replacement animals to ensure the herd size is maintained. Consequently, the intensity of greenhouse gas emissions from livestock farming can be reduced through higher efficiency and production gains resulting from improved livestock health, reduced mortality, and, regarding cows, longevity.

Presently, two research streams concerning GHG emissions and animal health can be observed:

1. Effects of animal health and losses on GHG emissions [26,29,30];
2. Priorities for modelling livestock health in the context of climate change [33–38].

The objective of the present paper is to describe issues related to the first question. We wish to demonstrate the influence of animal diseases on the yields of lactating cows and on GHG emissions intensity (CO_2eq per kg milk). Similar interactions were examined by the Global Research Alliance on Agricultural Greenhouse Gases [39].

2. Importance of Feed Intake in Conjunction with Animal Health

A high feed and energy intake is the most important prerequisite for a more efficient conversion of feed into food of animal origin, and therefore leads to high animal yields. Increased feed intake may

contribute to a greater energy and nutrient intake and may improve the ratio between energy available for performance (animal yield) and maintenance, as demonstrated for dairy cows in Table 3.

Table 3. Model calculation to show the influence of dry matter (DM) intake (7.0 MJ of NE_L/kg DM) of dairy cows (body weight: 650 kg; 4% milk fat; maintenance 37.7 MJ NE_L/cow and day; [40] on energy intake, percentage of maintenance, milk yield, energy per kg of milk, as well as methane emissions and carbon footprints per kg of milk (without calf and heifer periods).

Parameter	Dry Matter Intake (kg/d)				
	10	15	20	25	30
Energy intake (MJ NE_L/d)	70	105	140	175	210
Energy maintenance (% of total NE_L[†]-intake)	53.9	35.9	26.9	21.5	18.0
Theoretical milk yield (3.3 MJ NE_L/kg milk)	9.8	20.4	31.0	41.6	52.2
MJ NE_L/kg of milk including energy for maintenance	7.1	5.1	4.5	4.2	4.0
Protein yield (g/cow and day)	333	694	1054	1414	1775
Methane emission[♦]					
(g/d)	240	360	480	600	720
(g/kg milk)	24.5	17.6	15.5	14.4	13.8
Carbon footprint (CF)[§] (g of CO_{2eq}/kg of milk)	825	605	530	495	475

[†] NE_L, net energy lactation; [♦] According to Flachowsky and Brade [3]: 24 g of CH_4/kg DM intake (DMI) for all diets; [§] Calculated on the basis of the greenhouse gas potential of CH_4 ($CO_2 \times 23$) and the calculations by Dämmgen and Haenel [41].

Concerning dairy cows, the portion of energy that is "inefficiently" used for maintenance decreased for cows which consumed 10 kg dry matter (DM)/day from about 54% to about 20% of their total energy intake when the cows consumed more than 25 kg DM (see Table 3). Furthermore, the CH_4 emission per animal and day increased, but the emission per kilogram of milk decreased (Table 3). These changes are accompanied by changes in ration composition (increase in concentrate proportion); furthermore, high-yielding cows probably also have a higher risk for more metabolic diseases—especially during the transition period (e.g., ketosis and ruminal acidosis [42,43]). Not only high yields and feed intake play a role in the development of ketosis. High body condition scores for management reasons are a key driver for the development of that disease [44]. Humer et al. [45] described in their review that the ration formulation for high-yielding dairy cows was often characterized by high concentrate levels in the diet in order to meet the energy needs of milk production. The result is a high provision of easily fermentable carbohydrates in the rumen. These circumstances may lead to the development of subacute rumen acidosis (SARA) when they are accompanied by an insufficient supply of physically effective fiber. Inadequate adaptation during ration changes, especially in the transition period when dramatic changes in DM intake (DMI) occur, further promote acidotic conditions in the rumen. Consequences of the development of SARA can include laminitis, parakeratosis of the rumen mucosa, or a reduction in milk fat content [46]. In this context, and especially with regard to the emissions per kilogram of milk, the advantages of higher feed intake and higher milk yields are questionable, as they trigger diseases and a shorter life expectancy of high-yielding cows. Therefore, nutritionally induced diseases should be considered in models to calculate the carbon footprints of dairy products.

3. Animal Yield and Emissions

Higher animal yields also result in higher emissions per animal, but in lower emissions per animal product (Table 4). Food of non-ruminant origin can be produced with lower GHG emissions, as shown in Table 4. The reasons for this are the higher CH_4 emissions caused by rumen fermentation. However, rumen fermentation enables ruminants to utilize roughages and by-products from agriculture (grain straw, etc.) and from the food industry (sugar beet pulp, etc.), which do not compete with nutritional supply for humans [47,48]. In a study by Zehetmeier et al. [49], GHG emissions from dairy cows were evaluated as a function of performance levels (6000, 8000, and 10,000 kilograms milk yield per cow per year) and interaction with beef production. This is necessary because at a higher milk production level there is a different output concerning beef, more precisely of culled cows and male

calves. The data from the mentioned study show that GHG emissions per kg milk fall with an increase in milk yield from 6000 kg (1.06 kg CO_2eq/kg milk) to 10,000 kg (0.89 kg CO_2eq/kg milk). However, due to the reduced output of beef, viz. of male calves and culled cows from milk production, emissions per kilogram of produced beef will increase from 10.75 kg CO_2eq to 16.24 kg CO_2eq as more beef must be produced from suckler cow husbandry if beef consumption remains constant. Therefore, this consideration of systemic limits when assessing animal performance and GHG emissions should not be underestimated, and further studies are needed to better evaluate the impact of increased animal performance on GHG emissions.

Table 4. Effects of animal species/categories on performances and CF per kg edible protein (see Table 1 for some further parameters [31]).

Protein Source	kg BW	Dry Matter Intake (kg/day)	Performance/Yield per Day	N-Excretion (% of intake)	Methane Emission; (g/d)	Emissions (kg/kg Edible Protein)		
						N	CH_4	CO_{2eq}
			Milk (kg/d)					
Dairy cow	650	9	5	80	250	1.0	1.6	45
		12	10	75	310	0.65	1.0	30
		16	20	70	380	0.44	0.6	16
		25	40	65	520	0.24	0.4	12
Dairy goat	60	2	2	75	50	0.5	0.8	20
		2.5	5	65	60	0.2	0.4	10
			Body weight gain (g/d)					
Beef cattle	350	6.5	500	90	170	2.3	3.5	110
		7.0	1000	84	175	1.3	1.7	55
		7.5	1500	80	180	1.0	1.2	33
Growing/fattening pig	80	1.8	500	85	5	1.0	0.12	16
		2.0	700	80	5	0.7	0.08	12
		2.2	900	75	5	0.55	0.05	10
Broilers	1.5	0.07	40	70	Traces	0.35	0.01	4
		0.08	60	60		0.25	0.01	3
			Laying performance (%)					
Laying hens	1.8	0.10	50	80	Traces	0.6	0.03	7
		0.11	70	65		0.4	0.02	5
		0.12	90	55		0.3	0.02	3

One of the first reactions of animals to diseases is a reduction of feed intake, followed by lower animal yields and higher GHG emissions per unit product, as shown in Tables 3 and 4. The principles discussed above are relevant for all diseases or disturbances of animal health and welfare.

4. Influence of Productive Life and Fertility on the CF of Lactating Cows

Animal fertility may also influence the GHG emissions from animal production systems [29]. Animal nutritionists have to find the balance between feed/energy intake and animal health. As an example, we assume a simple model for cows considering 27 months (820 days; daily body weight gain: 750 g) as the first calving age, lactation periods of 1, 2, 3, 5, or 8 years, and estimated early selections due to animal diseases. Emission data including the cows´ rearing period were calculated and are expressed as CF per cow and per kg milk in Table 5.

The total emissions per cow including their calf and heifer period increase with lactation numbers, but they decrease per kilogram of milk in consideration of the rearing period and the longer productive life of cows (Table 5). The decrease is dramatic up to the third lactation; more lactations also have an influence on the CF, but to a much lower extent than the first lactations. It can be concluded that animal losses may increase the CF per kg of milk. Animal breeding [50,51] and nutrition [29,31] may both influence animal health and may reduce the CF per kg milk or per kg edible protein. Poor fertility increases GHG emissions, as shown by some authors [45,51–54]. Garnsworthy [55] concluded that

improvements in the fertility of cows could reduce CH_4 emissions by 24%, primarily by reducing the number of replacements in the herd because of the longer productive life of the individual cow.

Table 5. Model calculation of the influence of the number of lactations of dairy cows (8000 kg milk per lactation; 650 kg body weight) on the emissions per animal and per kilogram milk in consideration of the calf/heifer period (calculation data by [3,41]).

Number of Lactations	1	2	3	5	8
kg CO_{2eq} (CF^1) per cow	10,200	15,400	20,600	31,000	46,600
g CO_{2eq} (CF^1) per kg milk	1280	960	860	770	730

^{1}CF = carbon footprint ($CO_2 \times 1$; $CH_4 \times 23$; $N_2O \times$ about 296).

5. Dairy Cow Diseases and GHG Emissions

There are only a few other studies whose authors examined the effects of dairy cow health and their implications on GHG emissions. Figure 1 provides a summarized overview of the influencing factors concerning the emission intensity of dairy cows that are addressed in this review.
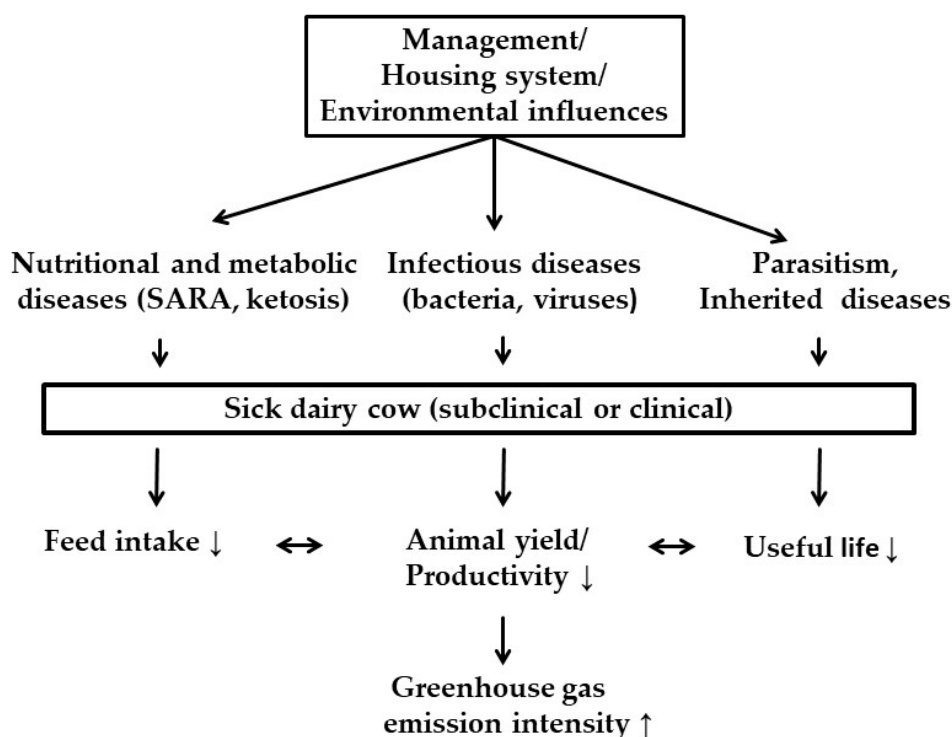
Figure 1. Influencing factors in the context of dairy cow health on variables (feed intake, animal yield/productivity, productive life) affecting the emission intensity (g CO_2 eq per kg milk) ($\downarrow$ = decrease; $\uparrow$ = increase). SARA: subacute ruminal acidosis.

More than 75% of dairy cow diseases in the US occur within the first month of calving [56]. Dechow and Goodling [57] found that in Pennsylvania 26.2% of all culls of dairy cows occur from day 21 before until day 60 after calving. Metabolic disorders around the calving period seem to be a very important topic for cow losses, low productivity, and high GHG emissions per kilogram of milk (see Table 5). Dänicke et al. [58] described in a review the connection between negative energy balance in early lactation and the immune system as well as the resulting consequences for the health of the dairy cow. A consequence of the situation of the negative energy balance during early lactation could be subclinical ketosis. A recent study by Mostert et al. [59] showed the impact of subclinical ketosis on GHG emissions. The authors concluded from their calculations an increase of the emissions by 7.9 kg

CO_2eq per ton of fat- and protein-corrected milk. A similar connection between foot lesions in dairy cows and GHG emissions is described by Mostert et al. [60].

Mastitis can be a consequence of this connection; therefore, Özkan et al. [61] analyzed healthy and diseased cows (subclinical mastitis; high somatic cell count) and found a 2% higher GHG emission per kilogram of milk for diseased cows (increase from 3.05 to 3.12 kg CO_2eq per kg milk). In a second study under production conditions in Norway, Özkan et al. [62] also showed the potential to reduce GHG emission intensity by 3.7% after a reduced somatic cell count from 800,000 cells/mL to 50,000 cells/mL.

In a study under conditions of the sub-Sahara region by Salomon et al. [63] it could be shown that the vaccination of dairy cows against lumpy skin disease or foot-and-mouth disease can be a very efficient and cost-effective method to reduce the emission intensity. In a recent study by Houdijk et al. [64] parasitism of rearing ewes (10,000 infective larvae of *Teladorsagia circumcincta* per animal) increased the calculated GHG intensity per kilogram of lamb weight gain for enteric methane by 11%, for manure methane by 32%, and for nitrous oxide by 30%. On average, parasitism increased the calculated global warming potential per kilogram of lamb weight gain by 16%. This is one of few studies with clear dose–response effects. More of this type of study should also be performed with dairy cows. For example, in dairy cows paratuberculosis is a latent problem worldwide. In a recent study by McAloon et al. [65] it was shown that positively tested dairy cows can have a milk yield that is reduced by 5.9%. Data on the emission intensity are not available, but it can be assumed that the nutrients would then no longer be adequately utilized and thus an effect on the emission intensity can be expected. Some more details of the interaction between animal health and GHG emissions are discussed by Hristov et al. [29].

6. Conclusions

To our knowledge, little or no attention has been spent on the effects of diminished yields and animal losses on GHG emission intensity with regard to health problems in dairy cows. In the case of illness in a dairy cow (clinical or subclinical), feed intake and milk yield are usually reduced. For this reason, GHG emissions then increase per kilogram of product. An extended productive life is desirable to achieve a reduction in emission intensity. It remains difficult to consider animal losses in terms of GHG emissions. Apart from the dead animal, we also have to consider the GHG emissions for the production of feed the dead animal had consumed during its life. More data that consider animal health up to animal losses seem to be necessary for a better quantification of GHG emission intensity.

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