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ASSESSMENT OF GREENHOUSE GAS EMISSIONS FROM DAIRY FARMING USING THE COOL FARM TOOL

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ABSTRACT. Climate change is one of the greatest challenges mankind has ever faced and could lead to potentially devastating global problems, with a need for urgent mitigation and adaptation. Agriculture, especially livestock farming, is a major driver of climate change through its contribution to the total emissions of greenhouse gases (GHGs). The dairy sector has been identified as an important source of GHG emissions, mainly via carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). In this study, total CO_2 equivalent (CO_2e) emissions were assessed from a dairy farm (65 dairy cows) located in Romania using the Cool Farm Tool calculator (CFT). We specifically aimed to calculate: (1) the total CO_2 equivalent (CO_2e) and CO_2e per kg FPCM (fat- and protein-corrected milk); (2) methane emissions from enteric fermentation; (3) GHGs resulting from feeding practices; (4) GHGs from manure management; and (5) a simulation of two different scenarios and their impact on GHG emissions. Our results showed annual GHG emissions of 553,170 kg CO_2e, almost half of which were released through enteric fermentation. Lactating cows were the major contributor to total GHG emissions, while heifers released the lowest emissions. The two scenarios simulated in this study showed that both the changes made in dairy diet composition and livestock manure management could result in lower GHG emissions. These results confirm the importance and utility of the CFT for the quantification of GHG emissions in dairy farms and its important role as a decision support tool to guide the adoption of good agricultural practices.

Keywords: dairy; greenhouse gases; emissions; climate change; enteric emissions; Cool Farm Tool.

INTRODUCTION

Climate change is one of the most pressing environmental concerns mankind has ever faced and could lead to potentially devastating global problems, with the need for urgent mitigation and adaptation. Increasing evidence indicates the contribution of agriculture to climate change, showing that this sector accounts directly for 10–12% of anthropogenic GHG emissions (Hillier *et al.*, 2011; IPCC, 2007) and for around 70% of land use change emissions (Frank *et al.*, 2017). The latest statistical inventory released in 2020 by Eurostat (Eurostat, 2020) showed that agriculture accounted for 11.4% of the European Union's 27 countries' total GHG emissions in 2020. According to the same statistical database (Eurostat, 2020), methane (CH_4) had the highest contribution to total GHG emissions from agriculture, totalling over 55% of all emissions. The Global Methane Assessment (2021) pointed out that methane emissions from livestock are the largest source of agricultural CH_4 emissions worldwide, accounting for 32% of CH_4 emissions from this sector (UNEPCCAC, 2021). Therefore, agriculture and especially cattle production, must be an integral part of any global strategy to keep global warming below 2°C, possibly to 1.5°C (Frank *et al.*, 2017). The targeted mitigation potentials from livestock include two major technological changes related to the improvement of animal health and husbandry (through reduced enteric fermentation in ruminants) and livestock manure management (UNEPCCAC, 2021). It is estimated that enteric fermentation alone accounted for emissions of 87–97 Tg CH_4/year from 2000–2009 (Chang *et al.*, 2019; Wolf *et al.*, 2017). This highly evolved process specific to ruminants occurs during digestion (in the rumen) when microorganisms decompose and break down food and fibres, producing high amounts of methane as a by-product.

Therefore, for a successful and accurate GHG assessment, it is of outstanding importance to consider the complexity of the dairy production system (Sejian *et al.*, 2018), involving the production system, the herd, grazing, feed, manure, energy and transport. This type of detailed evaluation could be performed more easily and accurately using specialised tools, such as the Cool Farm Tool (CFT), an open-source GHG model with specific functions for dairy GHG assessment. Several peers have analysed and tested the suitability and accuracy of such models (Ibidhi and Calsamiglia, 2020; Rotz, 2018). Rotz (2018) evaluated several whole-farm models that estimate GHG from dairy farms, including the CFT. The author concluded that these tools could be useful for guiding decisions aimed at reducing farm gate GHG emissions.

The weaknesses of this type of model identified by the author are the failure to represent individual farm processes over the full range of possible conditions and their inability to capture interactions among sources.

Here, we aimed to assess the total CO_2 emissions from a dairy farm (65 dairy cows) located in Romania using the CFT. We specifically aimed to calculate: (1) the total CO_2e equivalent (CO_2e) and CO_2e per kg FPCM; (2) methane emissions from enteric fermentation; (3) GHG emissions resulting from feeding practices; (4) GHGs from manure management; and (5) a simulation of the impact of two different scenarios on GHG emissions.

MATERIALS AND METHODS

Location of the case study farm

The study was conducted in Transylvania Plain, Romania, characterised by a continental climate with annual average temperatures between 8 and 10°C, and annual average rainfalls between 500 and 650 mm/year. The Transylvania Plain is one of the most important regions in dairy production in Romania, with an average milk production of 8155 hectolitres in 2021 (INSSE, 2021).

Description of the Cool Farm Tool model

Assessments of GHG emissions from the dairy system evaluated in this case study were performed using the CFT, a complex open-source GHG calculator aiming to quantify on-farm GHG emissions and soil carbon sequestration (CFT, 2022), with specific functions for dairy GHG assessment.

This tool was developed by the Cool Farm Alliance based on empirical research. The CFT was designed as a farmer-focused GHG calculator, providing the proper decision support system required for the adoption of good agricultural practices.

Data requirements. The data needed to calculate dairy GHG assessments are related to the production system, herd specificities, grazing system, feed, manure management, energy inputs and transport, detailed below.

Production system. The data required for the description of the production system includes specific information regarding the main breed, total milk production and milk quality (fat content and true protein content).

Herd description. This sub-section requires information concerning the average number of animals on the farm for the reference year, the number of animals sold and the number purchased, classified by cattle category (dairy calves, heifers, milk cows, nursing / suckling cows, dry cows and meat calves).

Grazing system. The data required for the description of the grazing system includes information regarding the amount of grazing time, total days and average hours per day during the grazing period and the selection of the grazing type and grass quality.

Feed inputs. This sub-section requires information concerning dry matter intake and includes two options for the user. The first method is designed for farmers/users who know the dry matter intake values. The second method addresses users who do not know the dry matter intake values, and by introducing specific data regarding their feed inputs, the CFT assists them through an estimation of these indices.

Manure management. The CFT requires data regarding manure management type (excluding grazing) for each animal category in the herd. If no manure management is selected for an animal category, grazing is automatically assumed by the tool.

Energy and processing. This sub-section requires information concerning the energy used as both a source of fuel and electricity.

Transport. As an important part of the dairy production system, transport is also included in the design of the CFT, requiring data about the inbound transportation of inputs, such as feed, fertiliser and outbound transportation of finished products to the processing site.

Results. Based on the data introduced by the user, the CFT provides information regarding the total GHG emissions (kg CO_2e), emissions per kg FPCM and detailed results about the contribution of each GHG source to the total GHG emissions and the performance of the dairy system through the feed conversion ratio index.

Dairy production system description

Farm data were collected through a semi-structured interview conducted on a dairy production system located in the Transylvania region, Romania. The semi-structured interview included questions that allowed us to collect information regarding the production system, herd composition, grazing system, feed, manure management, energy inputs and transport.

The dairy farm followed in this study had 65 dairy cattle from Montbéliarde breeding with a total milk production of 440,375 l (in the year 2021). The herd included 13 dairy calves, 12 heifers, 20 milk cows, 7 meat calves, and 13 nursing / suckling cows.

The animals were grazed 200 days/year, with an average of 12 hours/day, on a confined pasture, which provided high-quality forage. The 20 ha grassland grazed by the dairy cattle was fertilised with cattle manure and ammonium nitrate (33.5% N, granulated at a rate of 150 kg/ha). Average feed comprised 60% fresh grass (extensive), 15% maize silage, 5% compound dairy feed and 20% grass hay (off farm). Manure management (excluding grazing) was solid storage. The energy (fuel/electricity) used in this production system consisted of 1000 l diesel and 48,000 kWh from electricity (grid).

Simulating the options for GHG emission reduction in dairy farming

In addition to the assessments of GHG emissions from the dairy system evaluated in this case study under current operations, two different GHG emission scenarios were further simulated following interventions targeting two key problem areas: enteric CH_4 emissions and livestock manure management.

The scenario for enteric CH_4 emissions (S1) was based on changes in feed inputs (diet composition of dairy cows) and included feed comprising 60% fresh grass (extensive), 15% molasses, 5% compound dairy feed and 20% sorghum silage.

The scenario for manure management (S2) included the management of dairy manure by aerobic treatment through forced aeration.

The data recorded were processed using the post-hoc Tukey HSD Test from the R statistical package (RStudio Team, 2019), the effects being accepted as statistically significant if $p \leq 0.05$.

RESULTS

GHG emissions from the case study dairy system (under current operations)

The results obtained for the case study presented in this paper showed total GHG emissions of 553,170 kg CO_2e and an average of 1.22 kg CO_2e emissions per kg FPCM. Analysing the main sources of GHG emissions resulting from the farm management system, the highest contribution to the total GHG emissions was due to enteric fermentation, which accounted for 48% of total emissions (265,000 kg CO_2e), and feed production with 190,000 kg CO_2e, accounting for 34% of total emissions (*Figure 1*). Another great contributor to the total GHG emissions in this case study was manure management, with 40,400 kg CO_2e.

Methane from enteric fermentation contributed 9,490 kg to the total dairy footprint (*Table 1*). Among the GHG sources, feed production released the highest quantity of CO_2, with 183,000 kg, while the largest contributor of N_2O was the result of grazing, with total N_2O emissions of 97.70 kg.

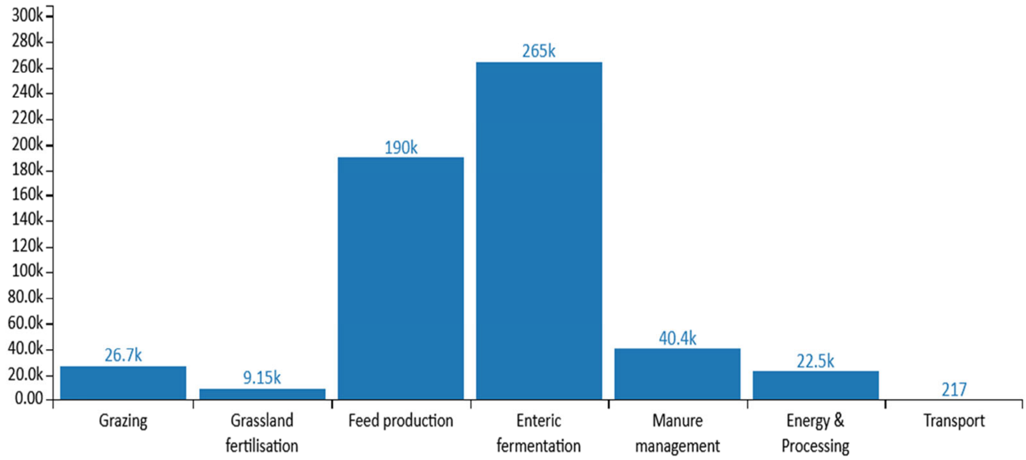

Figure 1 – Total emissions (kg CO_2e) recorded by the case study dairy farm under current operations, classified by the main source of GHG emissions: grazing, grassland fertilization, feed production, enteric fermentation, manure management, energy and processing, and transport. The data were calculated with Cool Farm Tool (CFT) (and are expressed in K – thousand kg CO_2e), found at https://app.coolfarmtool.org/dairy

Table 1 – Greenhouse gas (GHG) emissions recorded by the case study dairy farm, categorized by the main source of GHG emissions and GHG type

Sources	GHG (kg)			Per kg FPCM
	CO_2	N_2O	CH_4	
Grazing	0	97.70	0	0.06
Grassland fertilisation	3,430	20.95	0	0.02
Feed production	183,000	23.80	10.30	0.42
Enteric fermentation	0	0	9,490	0.58
Manure management	0	76.80	401.03	0.09
Energy & Processing	22.51	0	0	0.05
Transport	216.68	0	0	0

Note: data calculated with the CFT found at https://app.coolfarmtool.org/dairy

The results reached in this case study using the CFT showed that milk cows had the highest footprint, considering manure (68.4%), enteric fermentation (66.7%), grazing (59.8%) and feed (48.1%) emissions (*Figures 2* and *3*).

Dry cows were the second major contributor to farm GHG emissions due to emissions from manure sources (21%), enteric fermentation (16.2%), grazing (20.6%) and feed sources (31.3%).

Nursing cows made the lowest contribution to farm GHG emissions in the manure management category, with only 0.5% of the total emissions.

GHG emissions from nursing cows in other source categories included enteric fermentation (8.1%), grazing (10.2%) and feed (9.2%).

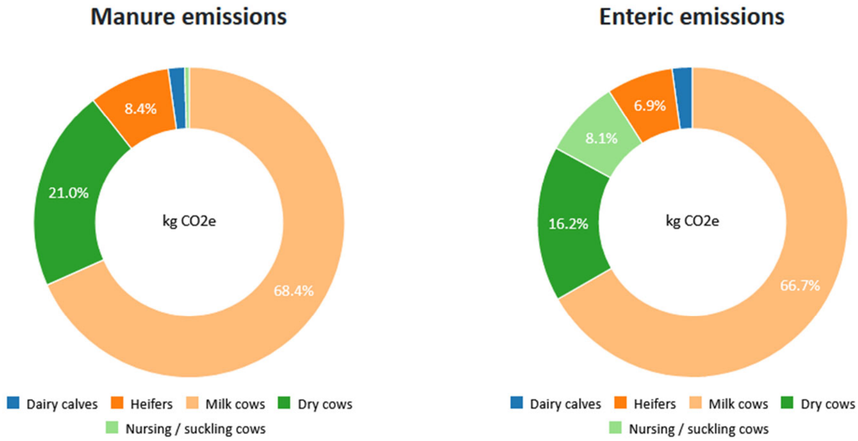

Figure 2 – Emissions resulting from dairy category and source—manure and enteric fermentation (data calculated with the CFT found at https://app.coolfarmtool.org/dairy)

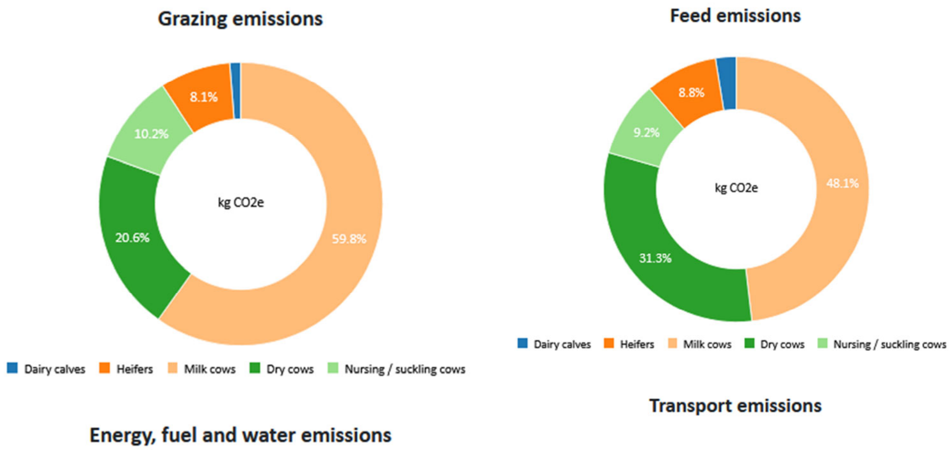

Figure 3 – Emissions resulting from dairy category and source - grazing and feed (data calculated with the CFT found at https://app.coolfarmtool.org/dairy)

GHG emissions under different simulated scenarios

The results reached in the S1 scenario using the CFT showed total GHG emissions of 418,370 kg CO_2e and an average of 0.93 kg CO_2e emissions per kg FPCM, while the changes simulated under the S2 scenario showed total GHG emissions of 528,450 kg CO_2e and an average of 1.17 kg CO_2e emissions per kg FPCM. Overall, all changes simulated under the S1 and S2 scenarios resulted in lower emissions compared to the values recorded under current operations (CS) (*Table* 2). The most significant decreases in GHG emissions were recorded under the S1 scenario, considering the CO_2 emissions, which were almost half as much in the S1 scenario compared to the CS.

Table 2 – GHG emissions classified by the main source of GHG and greenhouse gas type under different simulation scenarios

Sources	GHG (kg)								
	CO_2			N_2O			CH_4		
	CS	S1	S2	CS	S1	S2	CS	S1	S2
Grazing	0	0	0	97.70^{a}	89.27^{b}	85.30^{c}	0	0	0
Feed production	183,000^{a}	99,790^{b}	192,000^{a}	23.80^{b}	35.72^{a}	17.21^{c}	10.30^{b}	16.18^{a}	10.55^{b}
Enteric fermentation	0	0	0	0	0	0	9,490^{a}	7,700^{c}	9,050^{b}
Manure management	0	0	0	76.80^{a}	69.95^{b}	50.07^{c}	401.03^{a}	282.38^{b}	63.22^{c}

Note: data calculated with the CFT found at https://app.coolfarmtool.org/dairy. S1—scenario for enteric CH_4 emissions; S2—scenario for manure management. The effects were accepted as statistically significant if $p \leq 0.05$. Values within the same line (for a specific GHG) followed by a common letter are not significantly different according to the *t*-test.

The changes made in the diet composition of dairy cows (simulated under the S1 scenario) resulted in a lower contribution of enteric fermentation to the total dairy footprint compared to the value calculated for case study CS (*Table 2*). Additionally, a significant decrease in emissions by about 83,210 kg CO_2 was also reached in the S1 scenario. The changes simulated for manure management (S2) had high effects on GHG emissions, showing a decrease in emissions of about 338 kg CH_4 in S2 compared to the CS scenario (*Table 2*).

DISCUSSION

Increasing evidence indicates the contribution of the dairy industry to climate change, with approximately 15% (Munidasa *et al.*, 2021) to 18% (Sejian *et al.*, 2018) of global anthropogenic emissions. Therefore, in recent years, research has focused on evaluating total GHG emissions resulting from dairy production systems (De Vries *et al.*, 2019; Gerber *et al.*, 2011; Lorenz *et al.*, 2019). One of the major issues is providing a detailed description of the GHG sources involved in this production system. In this regard, specialised applications could assist farmers in this evaluation, but the selection of the most accurate ones could be a difficult task. The CFT is such a calculator with specific functions for dairy GHG assessment, which aims to provide the total GHG emissions resulting from an individual dairy system and the detailed GHG emissions by source. In this study, we performed an overall evaluation of a dairy farm with 65 animals to test the suitability of CFT for the calculation of GHG emissions. Our study showed that the dairy farm included in this research produced a total of 553,170 kg CO_2e and an average of 1.22 kg CO_2e emissions per kg FPCM (*Figure 1*). The values recorded with the CFT are similar to those reported by other studies, which have also pointed out values for GHG emissions for dairy between 335,405 and 1,975,412 kg CO_2e (Sejian *et al.*, 2018). Undoubtedly, the results are greatly influenced by cattle breed, herd (cattle number/categories) and management applied to the dairy system, but even so the values reached in this study are included in the range of values reported by previous research. For emissions per kg FPCM, recent studies published by the FAO and GDP (2018) have pointed out major differences between the values recorded by developed countries (an average of 1.4 kg CO_2e per kg FPCM) and those of developing countries (an average of 5.4 CO_2e per kg FPCM). Still, the CO_2e emissions per kg FPCM recorded in this study fell within these intervals.

Our results showed that methane from enteric fermentation contributed 9,490 kg to the total dairy footprint. These results are confirmed by previous findings, which also highlight the great contribution of enteric fermentation to the overall dairy footprint (Bellarby *et al.*, 2012; Hernandez, 2022; Munidasa *et al.*, 2021). Manure management was also an important contributor to total GHG emissions in this case study.

Paramesh *et al.* (2022) and Parajuli *et al.* (2018) raised concerns about the high GHG emissions from manure management in enterprises as diverse as large dairy, poultry and other livestock operations. A recent study performed by Capper and Cady (2020), aiming to compare the environmental impact of U.S. dairy cattle production in 2007–2017, also highlighted that the major contributors to total GHG emissions were enteric source and manure management (80%), with lesser contributions from cropping (7.6%) and fertiliser application (5.3%).

The CFT allows for emission comparisons among animal categories; in this case study, the highest GHG emissions were from milk cows.

Overall, the results achieved with the CFT are in accordance with those reported by previous research, highlighting the suitability and practical utility of this online tool for assessments aiming to provide an accurate evaluation of GHG emissions resulting from dairy farming. Similar findings were also highlighted by Hillier *et al.* (2011), who concluded that the CFT has numerous benefits (educational and practical), being useful as a first step of engagement for crop producers wishing to explore mitigation options. Rotz (2018) also agreed that the CFT could be useful for guiding decisions in the strategic design and tactical management of production systems. Following the assessment of GHG emissions from the case study farm under CS, two different GHG emissions scenarios were further simulated, following interventions targeting two key problem areas: enteric CH_4 emissions and livestock manure management. Changes in feed inputs greatly contributed to a reduction in both the total GHG emissions (from 553,170 kg CO_2e to 418,370 kg CO_2e), and the contribution of enteric CH_4 to these emissions. The change made to feed input consisted of the replacement of maize silage with molasses and grass hay with sorghum silage. Both feed products simulated in the S1 scenario are available and can be purchased from the local market, highlighting the suitability of applying these interventions in the Transylvania region. An important decrease in total GHG emissions was recorded in the S2 scenario, which followed the effect of changes enacted in manure management: from 100% solid storage to management of dairy manure by aerobic treatment through forced aeration. This manure management change resulted in a decrease in total GHG emissions from 553,170 kg CO_2e to 528,450 kg CO_2e. Altogether, these simulation scenarios showed that CFT could assist farmers and other stakeholders not only for an accurate assessment of GHG farm emissions but also as a decision support tool that allows the user to simulate the changes desired to be implemented on the farm level prior to their in-field implementation.

CONCLUSIONS

The results of this study showed total dairy GHG emissions of 553,165 thousand kg CO_2e, highlighting that enteric fermentation and feed management were the major contributors to the total dairy GHG footprint. These results are in line with previous research and confirm that the CFT model is a complex farm-focused GHG calculator that can deliver accurate results. We believe that the detailed assessments delivered by the CFT could provide the decision support required by farmers for the adoption of good agricultural practices, as demonstrated by the two simulated scenarios considered in this study.

Author Contributions: Conceptualization (R.V. and A.M.); methodology (R.V., A.M., M.R. and C.M.); analysis (A.M., C.M. and A.P.); investigation (A.M., M.R. and C.M.); resources (R.V.); data curation (A.P. and C.M.); writing, review (A.M., M.R. and A.P.); supervision (R.V. and C.M.).
All authors declare that they have read and approved the publication of the manuscript in this present form.

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Conflicts of Interest: The authors declare no conflict of interest.

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