ISSN 1028-334X, Doklady Earth Sciences, 2021, Vol. 497, Part 1, pp. 266–271. © Pleiades Publishing, Ltd., 2021.
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GEOECOLOGY

Carbon Calculators as a Tool for Assessing Greenhouse Gas Emissions from Livestock

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Presented by Academician Yu.A. Yuldashbaev November 6, 2020

Received November 6, 2020; revised December 18, 2020; accepted December 19, 2020

Abstract—Carbon calculators are programs for calculating greenhouse gas emissions (a carbon footprint) from agricultural production on the farm scale. They are created on the base of the IPCC methods but have not been used in Russia yet. The purpose of this study is to analyze the effectiveness of their application to assess emissions from livestock production and to develop recommendations for their reduction. The four most common calculators, i.e., the Cool Farm Tool, the AgRE-Calc, the Farm Carbon Calculator, and Ex-Act, were selected as the study objects. Among them, the Cool Farm Tool is recognized as the most convenient and effective, while the AgRE-Calc and the Farm Carbon Calculator do not fully present the technological features of animal husbandry. Ex-Act is ill-suited for the livestock sector because it is based on changes of land use. According to model experiments, the most efficient type of farming in terms of reducing greenhouse gas emissions is full grazing, in which manure is left in the fields, and there are no expenses for production of additional feed. In this case, the emissions are reduced by 2.45 and 0.84 t CO_2-eq./head-yr for cows and horses, respectively (the Cool Farm Tool); as well as by 0.53 and 0.42 t CO_2-eq./head-yr for cows and horses, respectively (the Farm Carbon Calculator). However, this leads to extensive farm management. The second variant is changing the diet, including expenses for feed production: exclusion of green crops from the diet in case of keeping in stalls will reduce emissions by 0.05 (the AgRE-Calc) to 0.14 (the Cool Farm Tool) t CO_2-eq./head-yr, and exclusion of silage will lead to a decrease by 0.96 t CO_2-eq./head-yr, although such decisions may worsen the diet balance. To reduce greenhouse gas emissions from livestock production, it is recommended that the number of domestic animals be gradually decreased. The Farm Carbon Calculator, the AgRE-Calc, and Ex-Act significantly overestimate the intensity of greenhouse gas sequestration by forests. Because of the discrepancy in the estimates between the calculators, they should be used comprehensively.

Keywords: carbon dioxide, methane, nitrous oxide, cows, sheep, horses

DOI: 10.1134/S1028334X21030119

INTRODUCTION

Carbon calculators are the programs for calculating greenhouse gas (GHG) emissions, also known as the carbon footprint, from agricultural production on the scale of a farm. They usually consist of a few program modules related to livestock and plant production, waste management, and use of fuel and energy, and are constructed by the principle of a drop-down menu and entering a few variables into fixed cells. The calculators appeared in the 2010s after the IPCC methods had been published and began to be used actively throughout the world, starting from the European countries. But they are not common in Russia, and there are not any papers on this subject that have been published in Russian yet.

According to our forecasts, the use of carbon calculators in our country will be especially urgent soon, since such technologies may help decrease the GHG emission from livestock, although it will never decrease to zero. According to the data of the The National report on cadastre of anthropogenic emissions from the sources and absorption by the greenhouse gas absorbers, methane emissions from enteric fermentation of domestic animals amount to more than one-third of GHG emissions from agriculture. In 2018, they were equal to 49.0 mln t CO_2-eq. when the total emission from the sector was 126.7 mln t CO_2-eq. The introduction of a carbon tax (under the principles of the Paris Agreement) will negatively affect farms and may threaten national food security [2].

From our point of view, there are five benefits of carbon calculators:

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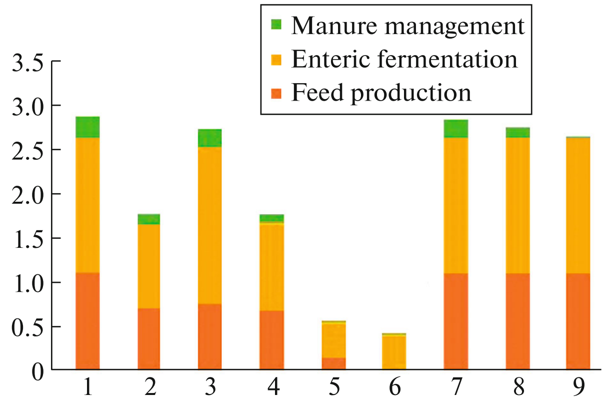

Fig. 1. Results of estimations for cows based on the Cool Farm Tool program, t CO_2-eq./head-yr. (1) Initial variant (complete diet, manure is composted); (2) half of the number of livestock; (3) without green crops (silage, grain, and straw); (4) without green crops and silage (grain and straw); (5) without green crops, silage, and grain (straw); (6) full grazing; (7) storage of solid manure; (8) 50% of manure is stored, 50% is spread; (9) spread of manure over the fields.

• They function online and are free to access.

• They make it possible to estimate and to compare the flows between each other and to forecast their intensity.

• They are easy-to-use.

• They give assessment on a farm scale.

• They can be used for a wide range of farms.

In our opinion, we should mention the following drawbacks of carbon calculators:

• The internal parameters and embedded equations cannot be adjusted.

• They have consideration of only anthropogenic factors of emission.

• They disregard the climate parameters and features of natural zones.

• The modules of carbon sequestration are poorly presented.

In our opinion, the calculators are ill-suited for assessing GHG emissions from crop production, since they do not allow considering the technological features of farming in the different geographical zones (primarily, the changes in the planting and harvesting dates), while in the livestock production sector, an averaged approach is quite reasonable, as the animals are kept in barns under controlled microclimate conditions and are fed a developed diet.

The purpose of our study was to analyze the efficiency of using carbon calculators for assessing GHG emissions from livestock and to develop recommendations for decreasing them.

MATERIALS AND METHODS

As study objects, we selected the four most common carbon calculators (Table 1), which were given the highest appraisal in categories of practical, usable, rigorous, and complete in the Environment and Rural Affairs Monitoring and Modeling Program of Great Britain [9]: the Cool Farm Tool, the AgRE-Calc, the Farm Carbon Calculator, and Ex-Act. The calculations were performed by the example of three farms, data from which their managers kindly allowed us to use (Table 2). During the computer experiments on determining the optimal way of animal husbandry in order to reduce GHG emissions, the initial actual parameters were combined with theoretical possible ones.

RESULTS

Based on the structure of the calculators, two ways of their use are beginning to emerge:

• calculation of the carbon balance on a farm to find out if it is a source or a sink of GHG for the atmosphere,

• calculation of GHG emissions for assessing possible ways of their decrease, which can be reduced in three areas:

• a decrease in the number of domestic livestock,

• a change in their diet, including a reduction of expenses for feed production,

• a change in the manure management systems.

We note that the AgRE-Calc and Ex-Act report higher emission values, while the Cool Farm Tool and the Farm Carbon Calculator underestimate them (Table 3). The difference between the resulting values is 2.0–2.5 times for cows and 2.4–3.0 for sheep. For horses, it does not exceed 40%.

According to the data of the computer experiments, the most effective type of management for emission reduction is full grazing, in which manure is left in the fields and there are no expenses for the production of additional fodder. According to the estimates using the Cool Farm Tool, in this case, the emission decreases by 2.45 t CO_2-eq./head-yr for cows (Fig. 1) and by 0.84 t CO_2-eq./head-yr for horses (Fig. 2). The estimates based on the Farm Carbon Calculator correspond to an emission decrease by 0.53 t CO_2-eq./head-yr for cows and by 0.42 t CO_2-eq./head-yr for horses (Fig. 4). However, this variant implies extensive farming, the necessity of expanding the grazing land areas, and a decrease in productivity, which will eventually lead to economic losses. According to the AgRE-Calc data (Fig. 3), leaving manure in the fields will conversely increase GHG emissions by 0.73 t CO_2-eq./head-yr compared to its solid storage.

Interestingly, based on the results of calculations using the Cool Farm Tool, a decrease in GHG emissions can be reached by changing the principles of

Table 1. Comparative analysis of carbon calculators

Name		Cool Farm Tool	AgRE-Calc (Agricultural Resource Efficiency Calculator)	Farm Carbon Calculator	Ex-Act (the EX-Ante Carbon-balance Tool)
Developer		Conceived by Food Lab, Unilever, and University of Aberdeen, designed and developed by Antithesis Group, managed by Cool Farm Alliance	SAC Commercial Ltd, business unit of Scotland's Rural College	Developed by Farm Carbon Cutting Toolkit, funded by Esmée Fairbairn Foundation	FAO (Food and Agriculture Organization)
Year of creation		2011	2014	2012	2010
Link to a web resource		https://app.coolfarmtool.org/	https://app.agrecalc.com/index.php	https://calculator.farmcarbontoolkit.org.uk/	http://www.fao.org/tc/exact/ex-act-home/en/
Form of operation		online	online	online	off-line, Excel
Separate considering of three GHGs		yes	yes	no	no
Considering of feeding and diet		yes	yes	no	partially
Considering of grazing		yes	no	no	partially
Considering of sequestration		no	yes	yes	yes
Compliance with the IPCC method		Tier 1 or 2 with respect to input data	Tier 2	Tier 1	Tiers 1 and 2
Principle of assessment		Per unit of product	In total per farm, per area unit, and per unit of product	In total per farm	In total per farm and per area unit
Presentation of results		Separately for each GHG in kg and t CO_2-eq.	Separately for each GHG, t CO_2-eq.	In total, t CO_2-eq.	In total, t CO_2-eq.
Animal species	Cows	yes	yes	yes	yes
	Horses	yes	no	yes	yes
	Pigs	yes	yes	yes	yes
	Sheep	yes	yes	yes	yes
	Poultry	yes	yes	yes	yes

Table 2. Study objects

Name	SPK Amosovskii	Farm of E.A. Gusev	OAO Chapaev Chuvashian Stud Farm
Location of farm	Kursk oblast, Medvenka region	Ryazan oblast, Sapozhok region	Republic of Chuvashia, Yadrin region
Manager	V.S. Kuznetsova	E.A. Gusev	R.N. Malov
Animal species	Cows, dairy system	Sheep	Horses
Animal number (in 2019)	1837	700	60
Animal keeping	In paddocks; diet based on grain, silage, straw, and green crops	Free grazing with supplementary feeding with grain	Free grazing with supplementary feeding with oats
Manure management	Manure is composted with subsequent delivery to fields	Manure is left in the pasture	Manure is left in the pasture

Table 3. Results of calculations for the initial variant of farming, t CO_2-eq./yr

Species of animals	Calculator	Cool Farm Tool		AgRE-Calc		Farm Carbon Calculator		Ex-Act	
	Company	per farm	per head	per farm	per head	per farm	per head	per farm	per head
Cows	SPK Amosovskii	5278	2.87	12320	6.71	5040	2.74	10611	5.78
Sheep	Farm of E.A. Gusev	95	0.16	280	0.40	122	0.17	343	0.49
Horses	Chuvashian Stud Farm	81	1.35	–	–	68	1.13	95	1.58

livestock feeding. The exclusion of silage from the diet will lead to an emission decrease by 0.96, and the removal of green crops will reduce emissions by 0.14 t CO_2-eq./head-yr (Fig. 1). Thus, the rejection of these two types of fodder and the use of only grain and straw will make it possible to decrease emissions by approximately the same degree as does livestock reduction by two times. However, in this case, the diet balance may worsen, which will lead to decreased livestock productivity. Conversely, in the AgRE-Calc, there is no significant difference between the diet variants (the exclusion of green crops from the diet in in case of keeping in stalls of livestock will reduce GHG emissions by only 0.05 t CO_2-eq./head-yr); i.e., in fact, the expenses for production of 1 kg of any fodder and consequently the intensity of GHG emissions are equivalent to each other.

On the farms under consideration, either there are not carbon sinks or there are scarce data on them. Therefore, as an example of compensation of GHG emissions from livestock production, we present standard specific carbon sequestration in forests. The Farm Carbon Calculator assesses the possible sequestration of 5.66, 5.84, and 6.19 t CO_2-eq./ha-yr in coniferous, mixed, and broad-leaved forests, respectively, and 3.80 t CO_2-eq./ha-yr in perennial crops. Thus, each hectare in the forest compensates for GHG emissions from 1.4–2.3 cows or 22.3–36.4 sheep. In addition, according to the data from this calculator, the rise of the soil organic carbon content for each 0.1% corresponds to sequestration of 255.2 t CO_2-eq./ha-yr.

The AgRE-Calc estimates carbon sequestration in coniferous and broad-leaved forests at 10.89 t CO_2-eq./ha-yr, which is equivalent to GHG emissions from 1.6 cows and 27.2 sheep. As we mentioned above, Ex-Act does not assess the current state on a farm but calculates the changes in the emission caused by the execution of a certain project. On this principle, we established that when croplands are converted to grasslands, 12 t CO_2-eq./ha-yr are sequestered; when degraded lands are converted to perennial croplands, 20 t CO_2-eq./ha-yr are sequestered; when grasslands turn into forests, 68 t CO_2-eq./ha-yr are sequestered, and when croplands are converted to forests, 81 t CO_2-eq./ha-yr are sequestered. This conforms to the compensation of GHG emissions from 2.1–75.2 cows or 24.5–165.3 sheep.

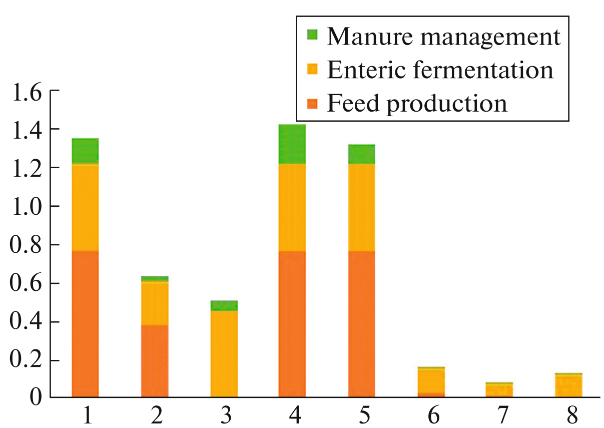

Fig. 2. Results of estimations for horses and sheep based on the Cool Farm Tool program, t CO_2-eq./head-yr. Horses: (1) initial variant (complete diet, manure is left in fields); (2) half of the number of livestock; (3) full grazing; (4) manure is composted; (5) 50% of manure is stored, 50% is spread; Sheep: (6) initial variant (grazing with supplementary feeding, manure is left in fields); (7) half of the number of livestock; (8) full grazing.

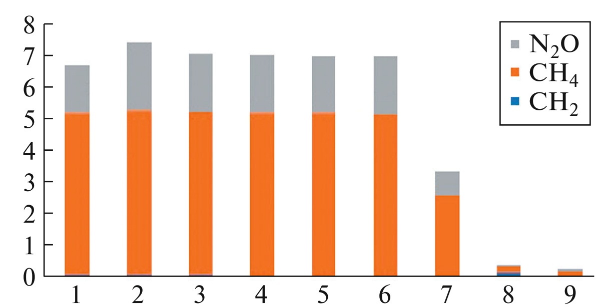

Fig. 3. Results of estimations for cows and sheep based on the AgRE-Calc program, t CO_2-eq./head-yr. Cows: (1) complete diet, storage of solid manure; (2) complete diet, spread of manure over the fields; (3) complete diet, 50% of manure is stored, 50% is spread; (4) without green crops (silage, grain, and straw); (5) without green crops and silage (grain and straw); (6) without green crops, silage, and grain (straw); (7) half of the number of livestock; Sheep: (8) grazing with supplementary feeding; (9) full grazing.

DISCUSSION

A significant difference between the computation results of the four calculators selected is recorded above. It is difficult to determine which of these estimates are more accurate, since in the other sources, the range of values is even wider. For example, in GOST (State Standard) R 56267–2014 "Greenhouse Gases: Quantifying Greenhouse Gas Emissions in Organizations and Reporting," the assessment factor of emissions from one cow is 1.89 t CO_2-eq./yr, which is much lower than the values obtained in this work. According to the data of the Russian researchers, keeping a dairy cow in our country leads to GHG emissions amounting, on average, to 5.13 t CO_2-eq./yr or 0.64 kg CO_2-eq./kg of milk [1]. These estimates are the closest to the Ex-Act results. According to the international data, a dairy cow of a local breed emits into the atmosphere 1.54 kg CO_2-eq./kg of milk, and a highly productive cow emits 2.63 kg CO_2-eq./kg of milk [7], which is greater by 1.5–2.0 times than the results of this study (0.44–1.03 kg CO_2-eq./kg of milk).

In terms of reduction of GHG emissions in the atmosphere, the option of free range grazing in pastures is the best for animals, although it is unsuitable in terms of developing intensive farming and maintaining the necessary level of production. In addition, it may cause soil degradation because of overgrazing. Taking into account that the results of estimations by different calculators for the manure management systems have a contradictory character and that to decrease the emissions by enteric fermentation seems impossible at present, we should admit that the GHG emissions from livestock production can be reduced by gradually decreasing the number of domestic livestock. On one hand, this might be ineffective in economic terms. On the other hand, this will help reduce the costs for plant production, since domestic livestock use precisely 60% of the global biomass yield [10].

A separate aspect is related to the estimation of potential GHG sinks on a farm or in neighboring ecosystems. We determined that each hectare can sequester carbon in the amount equal to that released by 1.4–2.3 cows (in case of keeping in paddock) or by 22.3–36.4 sheep (during grazing in a pasture). However, the calculators' output values considerably exceed the values from the official papers. For example, according to the data on the area of lands covered by forests [3] and GHG sequestration by forest lands [4], the specific carbon flow to forests can be estimated approximately. In 1998, the sequestration was 0.72 t CO_2-eq./ha-yr, and in 2008, it was 0.81 t CO_2-eq./ha-yr, which is much smaller than the output values of three calculators, comprising a block of GHG sequestration (the AgRE-Calc, the Farm Carbon Calculator, and Ex-Act). Thus, the carbon calculators considerably overestimate the intensity of GHG sequestration by forests.

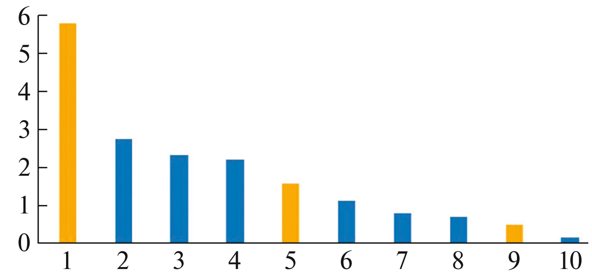

Fig. 4. Results of estimations using Ex-Act (yellow columns) and the Farm Carbon Calculator (FCC) (blue columns), t CO_2-eq./head-yr. (1) Ex-Act, cows; (2) FCC, cows, manure is composted; (3) FCC, cows; manure is left in the pasture; (4) FCC, cows; manure is spread over fields; (5) Ex-Act, horses; (6) FCC, horses; manure is composted; (7) FCC, horses; manure is left in the pasture; (8) FCC, horses; manure is spread over fields; (9) Ex-Act, sheep; (10) FCC, sheep.

It is important to realize that the calculators neither give advice nor suggest modifications in farm management. Moreover, they react differently to the changes introduced by a user into the modeled system; therefore, their estimates can vary significantly. Even in cases when the assessment indices of the different calculators on a farm scale seem the same, the components of these estimates can differ. Consequently, we should be careful with the strategies calculated for reducing GHG emissions and mitigating climate changes [11].

In our opinion, two carbon calculators, the Cool Farm Tool and the AgRE-Calc, should be recognized as the best in terms of convenience of use, the possibility of representing the results as GHG flows, record keeping of different aspects, and the range of coverage of technological features in livestock raising. The minor weak points of the AgRE-Calc are the impossible record keeping of features in livestock grazing and the absence of a module for horses.

The Cool Farm Tool is interesting as it allows us to introduce and analyze the data outside the scope of the standard inventory methods [8]. It is widely used throughout the world. For example, it was used to assess GHG emissions in India [12], to quantify the required amount of nitrogen fertilizers for corn in Kenya and Ethiopia [5], and to reduce GHG emissions by 25% from egg production in Great Britain [13]. However, it can assess the GHG sequestration.

The Farm Carbon Calculator simplifies the approach to estimating the carbon footprint, does not decompose it into greenhouse gases, and does not record the features of livestock feeding and grazing. This can be a matter of some difficulty for an agricultural producer in making management decisions, since it is not clear which flow relates to a particular technological operation, although the presence in it of a module of carbon sequestration by forests and perennial crops is an unconditional positive characteristic.

Ex-Act is hardly applicable in the livestock section, as it is oriented to the assessment of changes in land use. It estimates carbon balance from GHG emissions and their sequestration, while the principle of its operation is based on comparison of the situation before and after project implementation [6]. Ex-Act records certain characteristics of livestock raising (feeding practice, use of food specific agents, breeding), but a user should add their influence on GHG emissions in percentage terms as input data, which will certainly cause difficulties.

CONCLUSIONS

We recognize that the Cool Farm Tool is the most suitable carbon calculator for estimating GHG emissions from livestock on a farm scale. In the AgRE-Calc and the Farm Carbon Calculator, the technological features of livestock raising are not presented fully enough. Ex-Act is ill-suited for the livestock sector, as it is based on the change of land use.

Because of discrepancies between the calculators concerning changes in the diet and manure management, they should be used comprehensively. Based on the features of each farm, to reduce greenhouse gas emissions, we recommend transferring domestic livestock to grazing in a pasture, changing the diet, or gradual decreasing their number.

FUNDING

This work was supported by the Russian Science Foundation, project no. 20-76-00023, and was carried out under a State Assignment of the Institute of Geography, Russian Academy of Sciences, project no. 0148-2019-0009.

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Translated by L. Mukhortova