Model Intercomparison of COMET-Farm, Cool Farm Tool, DNDC, and RothC

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Abstract

In this model intercomparison, I compare the carbon emissions data outputs of COMET-Farm, Cool Farm Tool, DNDC, and RothC using the same agronomic data inputs. The objective of this comparison is to provide a guide of the similarities and differences of tools quantifying carbon sequestration and greenhouse emissions on agricultural land. I used data from the Main Cropping System Experiment at the Kellogg Biological Station from the Conventional treatment, the No-Till treatment, and the Biological treatment, which has biological inputs with a winter cover crop. The project showed that for the Conventional treatment and the No-Till treatment, Cool Farm Tool, COMET-Farm, and DNDC elicited similar results. For the Biological treatment, the outputs differed by 163%, between the carbon *sequestration* output of COMET-Farm and the carbon *emissions* output of DNDC. For RothC, I was unable to separate the results by treatment.

Background

Background on COMET-Farm

COMET-Farm is a whole farm and ranch carbon and greenhouse gas accounting system developed by the US Department of Agriculture's Natural Resources Conservation Service and Colorado State University.[1] Underlying COMET-Farm is soil information from Web Soil Survey and the DayCent simulation model.[2] DayCent is a daily time step model for biogeochemical processes, simulating the major processes that affect soil organic matter, such as plant production, water flow, nutrient cycling, and decomposition. DayCent has submodels for nitrification and denitrification, CH_4 oxidation (though CH_4 emissions don't appear to currently be reported by COMET-Farm), and soil water and temperature.[3] Some current literature reports

[1] "Commonly Used NRCS Tools - COMET-Farm | NRCS."
[2] Paustian et al., "Farm-Scale Full GHG Accounting with the COMET-Farm Tool."
[3] Gryze et al., "Simulating Greenhouse Gas Budgets of Four California Cropping Systems under Conventional and Alternative Management," 1806.

that DayCent overestimates and underestimates N_2O emissions, often due to fertilizer applications.[4,5]

COMET-Farm currently has a number of different users. It is the official greenhouse gas quantification tool of the USDA.[6] Nori, a carbon removal marketplace that pays farmers to store carbon in their soil, uses COMET-Farm to model how much carbon was removed from the atmosphere and stored in soil.[7] The California Department of Food and Agriculture's Healthy Soils Program uses a specialized version of COMET-Planner, which gives outputs at the county level based on a sample-based approach and model runs in COMET-Farm.[8]

Background on Cool Farm Tool

Cool Farm Tool is an "online greenhouse gas, water, and biodiversity calculator for farming."[9] For this project, I used the CFT greenhouse gas emissions calculator. Cool Farm Tool is managed by the Cool Farm Alliance. The original intellectual property owners, and developers of the first version in Microsoft Excel, were the Sustainable Food Lab, Unilever, and the University of Aberdeen.[10]

The tool calculates emission estimates from N_2O emissions based on an empirical model compiled using over 800 global datasets, factoring in guiding drivers such as rate of N applied, soil texture, soil carbon, moisture, and soil pH. The soil carbon sequestration calculations are based on the results of published studies from over 100 global datasets. Fertilizer production emissions are based on recent peer-reviewed industry data.[11]

As an empirical model, Cool Farm Tool relies on correlative relationships in line with the mechanistic understanding of agricultural greenhouse gas emissions. The current understanding of biogeochemical cycles is implied in the model, but the system behaviors and interactions are not fully described. As a comparison, process-based models like COMET-Farm and DNDC aim to simulate the detailed physical and biological process of the agricultural ecosystem that would explain behavior within the system.[12]

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[4] Del Grosso, Halvorson, and Parton, "Testing DAYCENT Model Simulations of Corn Yields and Nitrous Oxide Emissions in Irrigated Tillage Systems in Colorado," 1386.
[5] Necpálová et al., "Understanding the DayCent Model," 120.
[6] "Commonly Used NRCS Tools - COMET-Farm | NRCS."
[7] "Nori."
[8] California Department of Food and Agriculture Healthy Soils Program and California Climate Investments, "Quantification Methodology."
[9] "The Cool Farm Tool | Cool Farm Tool," accessed April 18, 2021, https://coolfarmtool.org/coolfarmtool/.
[10] "Members | Cool Farm Tool," accessed April 18, 2021, https://coolfarmtool.org/cool-farm-alliance/members/.
[11] "Greenhouse Gases | Cool Farm Tool," accessed April 18, 2021, https://coolfarmtool.org/coolfarmtool/greenhouse-gases/.
[12] Henry D. Adams et al., "Empirical and Process-Based Approaches to Climate-Induced Forest Mortality Models," *Frontiers in Plant Science* 4 (2013): 1, https://doi.org/10.3389/fpls.2013.00438.

Background on DNDC

DNDC (DeNitrification-DeComposition) is a process-based computer simulation model of carbon and nitrogen biogeochemistry in agricultural ecosystems. There are two parts of the model. The first part consists of the soil climate, crop growth and decomposition sub-models. The second part consists of the nitrification, denitrification, and fermentation sub-models.[13] These parts create a model that can be used for predicting crop growth, soil temperature and moisture regimes, soil carbon dynamics, nitrogen leaching, and emissions of trace gases, such as nitrous oxide, ammonia, methane, and carbon dioxide.[14]

The DNDC model was first described by Changsheng Li of the University of New Hampshire in 1992.[15,16] Over the past 30 years, researchers throughout the world have adapted and modified the model to include different scenarios and diverse ecosystems such as forests, wetlands, and rice paddies.[17]

Background on RothC

RothC-26.3 is a computer model for the turnover of organic carbon in topsoils that are not waterlogged. The model accounts for the effects of soil type, temperature, moisture content, and plant cover. RothC was originally developed and parameterized to model the turnover of organic carbon in arable topsoils from the Rothamsted Long Term Field Experiments at the Rothamsted Research centre in the United Kingdom. Later the model was adapted to cover grassland and woodlands, as well as different soil types and different climates.[18]

From a user standpoint, it is helpful to know the varying characteristics between these modeling tools, because they each have different data input requirements and output their results in particular units. Researchers who are working with these tools will benefit from knowing how the same data will be treated by a variety of tools and can thus choose accordingly, based on their exact research requirements.

This model intercomparison is aimed at these kinds of users of greenhouse gas and carbon sequestration modeling tools. I examined each tool using the same set of agronomic input data to determine how each model interprets this information. This report will cover the process of developing and running the model intercomparison. Then I present the results of the model

[13] "User's Guide for the DNDC Model" (University of New Hampshire Institute for the Study of Earth, Oceans and Space, August 25, 2012), 6.
[14] "The DNDC Model" (Institute for the Study of Earth, Oceans, and Space, University of New Hampshire), accessed April 19, 2021, https://www.dndc.sr.unh.edu/.
[15] "DNDC" (International Soil Modeling Consortium), accessed April 18, 2021, https://soil-modeling.org/resources-links/model-portal/dndc.
[16] Sarah L. Gilhespy et al., "First 20 Years of DNDC (DeNitrification DeComposition): Model Evolution," *Ecological Modelling* 292 (November 2014): 52, https://doi.org/10.1016/j.ecolmodel.2014.09.004.
[17] Gilhespy et al., "First 20 Years of DNDC (DeNitrification DeComposition)," 52.
[18] K. Coleman and D.S. Jenkinson, "RothC - A Model for the Turnover of Carbon in Soil: A Model Description and Users Guide" (Rothamsted Research, June 2014), 5.

intercomparison, using the carbon emission results from each tool. I will briefly discuss the results and offer some thoughts on the model intercomparison. Lastly, given the constraints of this particular project, I will conclude with some ideas for future research.

Methods

To run each of the models, I used data from the Kellogg Biological Station (KBS) | Long-Term Ecological Research at Michigan State University. I used three treatment systems from the Main Cropping System Experiment, the signature KBS long-term experiment beginning in 1989. Each of the treatments are assigned to a 1 hectare plot in 6 replicate blocks and are planted in a corn - soybean - wheat rotation. Treatment 1 (Conventional) receives conventional levels of chemical inputs and is tilled with a chisel plow. Treatment 2 (No-Till) receives conventional levels of chemical inputs and no-till management. Treatment 4 (Biological) is a biologically-based input system with a winter leguminous cover crop and is managed with a rotary hoe to control weeds.[19] For ease of understanding, I will refer to the treatments simply as Conventional, No-Till, and Biological throughout the rest of this report.

One of the dominant soils of KBS is the Kalamazoo series, and is the soil profile that I used in this project. The Kalamazoo series is a fine-loamy, mixed, mesic Typic Hapludalfs.[20] Hapludalfs are the dominant upland soils of southern Michigan. Most were developed from glacial or glaciofluvial sediments.[21] This soil is characterized as well drained and moderately permeable in the upper part of the profile and rapidly permeable in the lower part.[22]

Southwestern Michigan, where KBS is located, has an annual rainfall of about 1,005 mm per year, with about half falling as snow. Mean annual temperature is 10.1 degrees Celsius. The KBS area is about 1600 hectares of cropping systems, successional communities, small lakes and wetlands.

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[19] "Main Cropping System Experiment - Main Site," KBS LTER, accessed April 19, 2021, https://lter.kbs.msu.edu/research/long-term-experiments/main-cropping-system-experiment/.
[20] "Soil Description," KBS LTER, accessed April 19, 2021, https://lter.kbs.msu.edu/research/site-description-and-maps/soil-description/.
[21] B.R. Khakural, G.D. Lemme, and D.L. Mokma, "Till Thickness and Argillic Horizon Development in Some Michigan Hapludalfs," *Soil Horizons* 34, no. 1 (1993): 6, https://doi.org/10.2136/sh1993.1.0006.
[22] "Soil Description," KBS LTER, accessed April 19, 2021, https://lter.kbs.msu.edu/research/site-description-and-maps/soil-description/.

Inputs

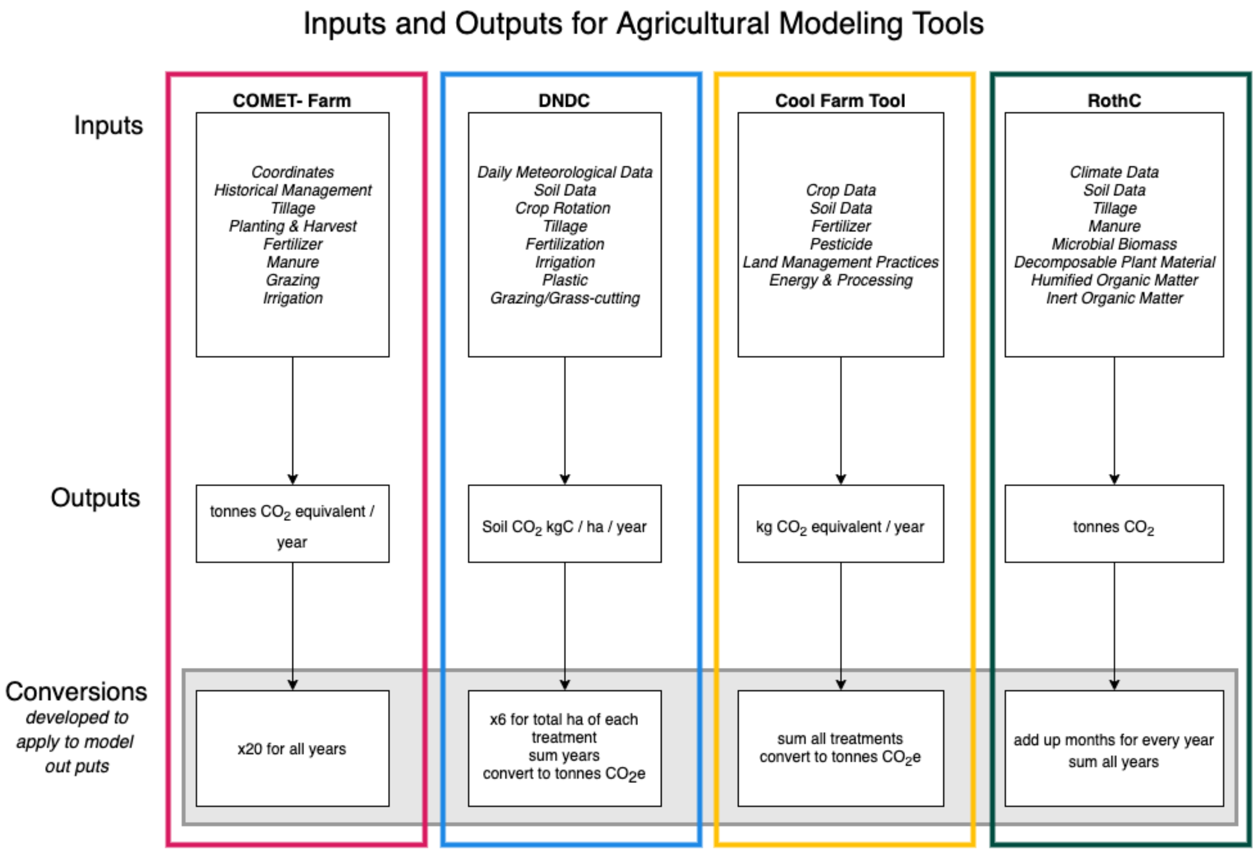

Figure 1. *This figure displays the inputs from the KBS data that I used for each model, the results that were output from each model, and the conversions that I applied in order to standardize the results.*

For each model, I created a spreadsheet of the required data of the three treatments (see Figure 1) using the data catalog and site information for the Main Cropping System Experiment on the KBS LTER website for the years 2000 to 2019.[23] For COMET-Farm, I pulled data on tillage, planting and harvesting dates, fertilizer inputs, and irrigation. For DNDC, I pulled daily meteorological data, soil information, planting and harvesting, fertilization, and irrigation. For Cool Farm Tool, I pulled cropping data, soil information, fertilizer and pesticide data, tillage practices, and estimated energy data for tractors using the tool. For RothC, I pulled meteorological and soil data as well as tillage data.

I ran each model and cataloged the results. Once I had the results, I parsed through the outputs to retrieve the relevant information for carbon emissions. Some of the models required collating monthly data into years, others required collating year by year data for the time period examined.

[23] The spreadsheet with data requirements for the models is available here.

Results

I converted all of the outputs to standardize the results in tonnes of CO_2 equivalent. I did some of the conversions by hand and some with the aid of the EPA Greenhouse Gas Equivalencies Calculator.[24] Once I had my results for each model, I uploaded all of the outputs into R Studio to create graphs to compare the models. RothC's interface did not allow me to distinguish by treatment so I was only able to get one result from that tool. I made a graph to compare the models by treatment, excluding RothC (see Figure 2). I created a graph with emissions totals to include the results from RothC (see Figure 3).

In Figure 2, the negative emissions of the tonnes of CO_2 equivalent for the Biological treatment shows that COMET-Farm calculated 94 tonnes of CO_2 equivalent of carbon sequestered, as opposed to carbon emitted.

As a comparison, I did a quick simulation of my results with FAST-GHG (Fertilizer And Soil Tool for GreenHouse Gases), A FAST calculator for climate change mitigation in agriculture.[25] I picked one plot (replicate 3) from each treatment to run through each crop of the corn-soy-wheat rotation. This tool uses the crop type, tillage practice, cover crop type, crop yield, and the mineral nitrogen fertilizer application rate to give estimates of the potential to reduce agricultural greenhouse gas emissions. For the Conventional fields, FAST-GHG found no change in greenhouse gas emissions compared to a baseline with no soil health or fertilizer optimization practices. FAST-GHG found that the corn and soy crops on the No-Till fields had a net decrease in greenhouse gas emissions of 0.09 Mg CO_2 equivalent per hectare per year and 0.07 Mg CO_2 equivalent per hectare per year, respectively, relative to a baseline with no soil health or fertilizer optimization practices. The wheat rotation on the No-Till fields, however, resulted in a net increase of 0.03 Mg CO_2 equivalent per hectare per year, relative to the baseline. The Biological treatment resulted in the largest decrease in greenhouse gas emissions. FAST-GHG found a net decrease of 0.25 Mg CO_2 equivalent per hectare per year for corn, 0.07 Mg CO_2 equivalent per hectare per year for soy, and 0.26 Mg CO_2 equivalent per hectare per year for wheat, all relative to a baseline with no soil health or fertilizer optimization practices.

[24] OAR US EPA, "Greenhouse Gas Equivalencies Calculator," Data and Tools, US EPA, August 28, 2015, https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator.
[25] "FAST-GHG," accessed May 14, 2021, https://d-woolf.shinyapps.io/FAST-GHG/.

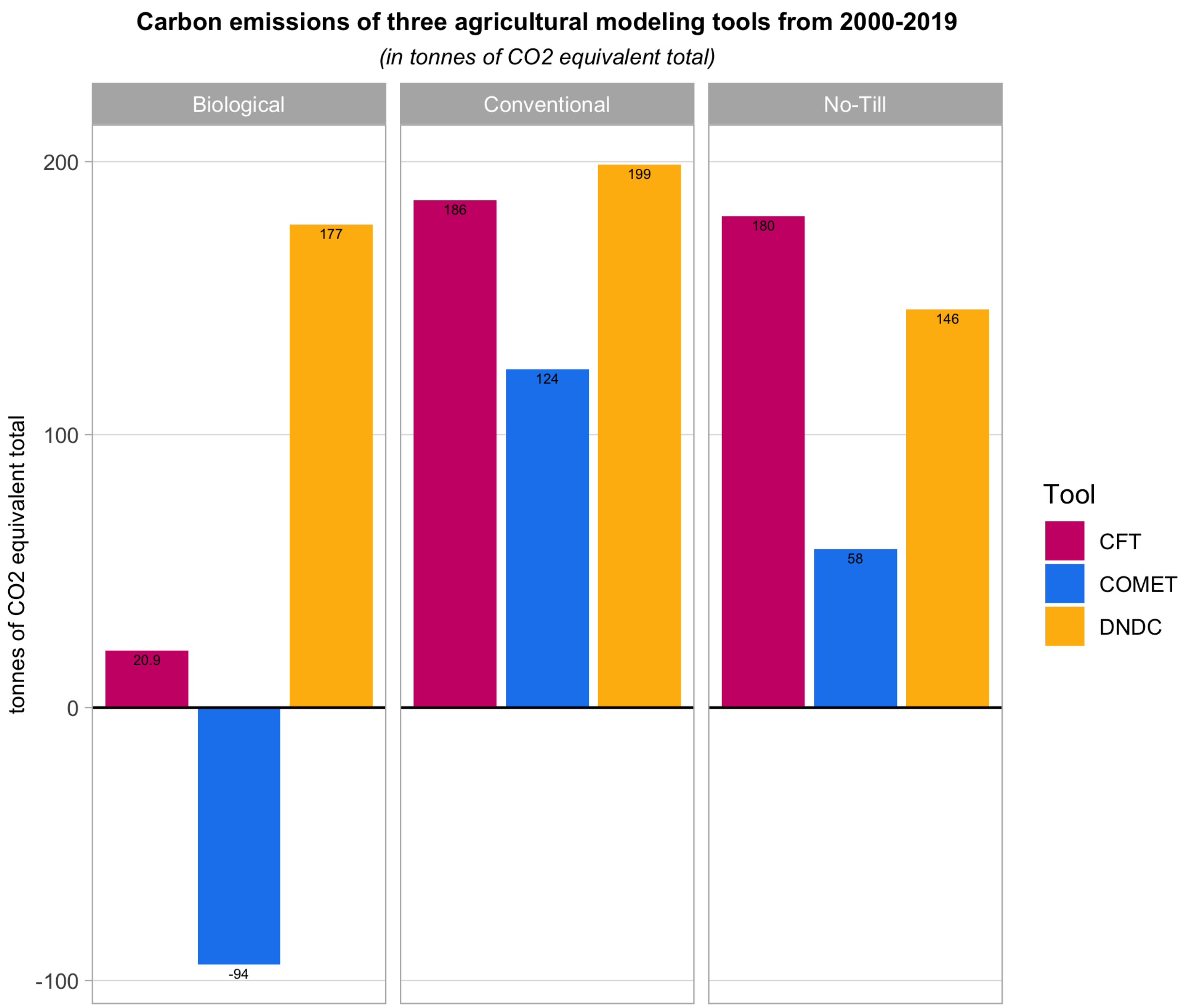

Figure 2. *Tonnes of CO_2 equivalent results by treatment (Conventional, No-Till, Biological) for Cool Farm Tool, COMET-Farm, and DNDC. Conventional and No-Till are similar for the three tools. The Biological treatment produced results differing by as much as 163%, where COMET-Farm calculated carbon sequestered 94 tonnes of CO_2 equivalent sequestered, compared to DNDC's 177 tonnes of CO_2 equivalent emitted.*

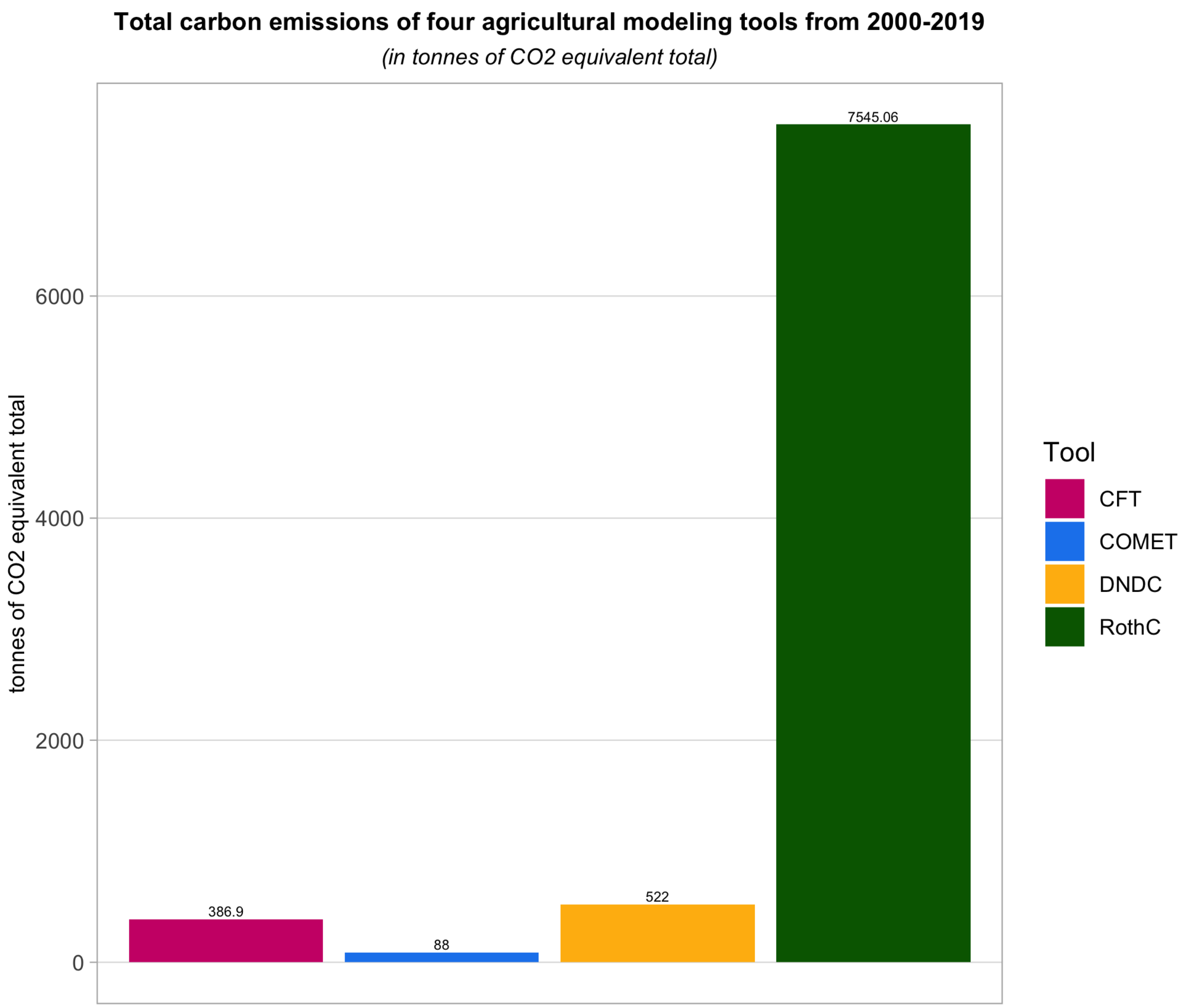

Figure 3. *Tonnes of CO_2 equivalent total results for Cool Farm Tool, COMET-Farm, DNDC, and RothC. RothC's results differ significantly from the other three tools.*

RothC's interface does not allow inputs to be distinguished by different treatments and thus I only have one set of results from the tool. Figure 3 shows the total results for all three treatments, Conventional, No-Till, and Biological, added together and compared with the results from RothC.

Discussion

This project showed that when comparing the Conventional and No-Till treatments, Cool Farm Tool, COMET-Farm, and DNDC produce similar results. For the Biological treatment, the outputs differed by 163%, between the carbon *sequestration* output of COMET-Farm and the carbon *emissions* output of DNDC. RothC had some limitations as a tool and did not allow me to distinguish between the treatments. Furthermore, RothC's results were significantly higher than the other three treatments when the results were added together. Without further examination into the tools, and into RothC in particular, I do not have insight as to why RothC produced this outcome.

In comparing the results from my project with the simulation using FAST-GHG, the results show that the results from the Biological treatment of carbon sequestration are a viable outcome. The Conventional treatment is FAST-GHG's baseline management so I expected the result of no change. The results from the No-Till treatment show small amounts of carbon sequestration compared to the results from COMET-Farm, Cool Farm Tool and DNDC. Given the more simplified inputs for FAST-GHG, this result makes sense.

The results from this model intercomparison are the first step for scientists and researchers working with tools such as COMET-Farm, DNDC, RothC, and Cool Farm Tool to understand some of the differences and similarities between them. Users of the tools care especially about each tools' particular inputs because some data is easy to collect and other information requires a heavier lift in order to gather or to produce.

Conclusion

Through this model intercomparison project I examined how the same agronomic input data would be interpreted by four different greenhouse gas emissions and carbon sequestration modeling tools. I found that for the Conventional treatment and the No-Till treatment, Cool Farm Tool, COMET-Farm, and DNDC were similar. For the Biological treatment, the outputs differed by 163%, between the carbon *sequestration* result of COMET-Farm and the carbon *emissions* output of DNDC. It is also noteworthy of the limitations of the RothC and its inability to distinguish between different agricultural management techniques.

I conducted this model intercomparison using data from Kellogg Biological Station, just 18 hectares, in southwestern Michigan operating under a corn-soybean-wheat rotation. Further study of different management practices, under a variety of ecosystems and climates, could be useful to see how the models respond to these changes, and compare the results to what I found from the KBS data. Considering the potential impact of regenerative agriculture techniques for healthy soil, practices such as cover crops and livestock integration, would be interesting for further study.

Given the significant disparity in total emissions results between RothC and the other three tools, further investigation into why this occurred could be potentially fruitful. The constraints of this project prevented me from doing an in-depth examination of this particularly unusual outcome.

Resources

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