Soil as a Resource
National Research Programme NRP 68

www.nrp68.ch
Wildhainweg 3, P.O. Box 8232, CH-3001 Berne

Executive Stakeholder Summary

Project number	40FA40_154247
Project title	COMET-Global: Whole-farm GHG estimation and environmental diagnostic platform
Project leader	Professor Johan Six, ETH Zurich

Contribution(s) to thematic synthesis:

☒ Soils and Food Production	☒ Soils and Environment	☐ Spatial Development	☒ Soil Data, Methods and Tools	☐ Soil Governance

Place, date: Zurich, 31st May 2017.

FNSNF
Swiss National Science Foundation

Background

There is a global concern related to increased levels of greenhouse gases (GHG) in the atmosphere, primarily carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4), and their impact on climate change. Intensification of agriculture due to technological advancement has doubled crop yields between 1970 and 2010, but also posed severe environmental problems. Cultivation of agricultural land has caused a historical loss of 50 Pg of soil organic C as CO_2. Soil organic C content is still declining in many cropland regions due to agricultural intensification and climate change. Soil and manure management, enteric fermentation, biomass burning, and rice cultivation have become the largest anthropogenic source of N_2O and CH_4, although there are regional differences in importance of these emission sources. In 2010, agriculture accounted for 5.0–5.8 Gt CO_2eq yr^{-1}, i.e., 10–12% of total global anthropogenic GHG emissions. In addition, direct energy use in agriculture and forestry accounted for about 2% of world energy consumption in 2009. Hence, there is a substantial potential to reduce agricultural contribution to environmental footprint by improved management and sustainable resource use. Particularly for area under crop production, there has been interest in agricultural management practices to enhance soil organic matter pools while decreasing losses of essential nutrients and soil GHG emissions.

Research proposed a number of management options that can significantly contribute to reducing soil GHG emissions from cropping systems, such as more efficient use of fertilizers, organic farming, reduced tillage intensity or no tillage, residue retention, winter cover cropping, and improved water and rice management. The biophysical mitigation potential of these practices need to be evaluated for individual cropping systems under specific pedo-climatic conditions, historical land use and management.

Ecosystem biogeochemical process based models provide the most effective way of quantifying GHG emissions responses to agricultural managements at the small to larger spatial and temporal scales. In recent years, these models and comprehensive decision-making tools integrated with these models have been used to identify and evaluate sustainable GHG mitigation options, their bio-economic feasibility in the agricultural sector, and support implementation of agricultural GHG mitigation activities that are an important part of regional and national climate change strategies.

Access to reliable and readily available estimates of the consequence of different land use and management practices on GHG emissions is a prerequisite for successful implementation of land use-based GHG mitigation strategies. Moreover, this information is needed at the level at which management decisions are actually made – at the field scale – and thus information decision systems should be: 1) easily and universally available, 2) usable by non-experts, 3) employ state-of-the-art technology and 4) be easily aggregated to larger scales.

Aims

The project aimed to develop and deploy a user friendly, state-of-the-art system COMET-Global for full GHG accounting, operational at the scale of an individual entity (e.g., farm, livestock operation) for partner countries including several EU members, the USA and Australia.

The GOMET-Global system development was based on an existing comprehensive whole-farm, full GHG web-based tool, COMET-Farm (http://cometfarm.nrel.colostate.edu), developed for the use in the USA. The COMET-Farm system provides a farm-scale quantification of all major agricultural GHG source/sink categories, including soil CO_2, N_2O and CH_4, enteric CH_4 from livestock, CH_4 and N_2O from manure management and CO_2 from on-farm energy use. The COMET-Farm employs a full spatial interface, facilitating the integration of a variety of geographically-distributed databases, user-supplied site-specific management data and a suite of models for estimating GHG sources and sinks, such as a widely-used process based DayCent model, for estimating soil GHG emissions, and a variety of other empirically-based emission models for other agricultural source categories.

ETH contribution to the COMET Global project aimed at:

a) Compilation of Swiss long-term experimental data sets with time series measurements of crop yields, soil organic C and soil GHG emissions, involving different management treatments (e.g., fertilization, crop type, tillage, manuring) for model parameterization and evaluation;
b) Parameterization of the DayCent model for common crops and management practices using long-term empirical data collected under various pedo-climatic conditions at four experimental sites in Switzerland and evaluation of the model's ability to predict long-term crop productivity, soil organic C dynamics and soil N_2O emissions in diverse Swiss cropping systems;
c) Compilation and configuration of spatial data sets covering Switzerland, providing driving variables as required by the DayCent model implemented in the COMET-Global system.
d) Compilation of Switzerland specific /default emission factors and parameters for non-soil GHG emission sources required for the COMET-Global country-specific application.
e) Compilation/categorization of land management practices for Switzerland to provide relevant management choices in the COMET-Global system.
f) Evaluation of long-term effects of management practices and their combinations on soil GHG emissions from Swiss agricultural soils at the site, regional and national scales in Switzerland.

Results

The empirical data were derived from four Swiss long-term experimental sites located in Therwil (DOK farming system trial; 1977-2013), Frick (Frick organic trial; 2002-2013), Changins (P29C tillage trial; 1969-2013) and Reckenholz (FAST trial; 2009-2013). These long-term experiments have evaluated effects of various farming systems and soil management practices. The number of treatments, factorial design and long-term duration of long-term experiments provided a robust data set for the DayCent model parameterization and evaluation across a range of management practices and pedo-climatic conditions in Switzerland. The DayCent model was parameterized for main crops grown in Switzerland and its ability to predict crop yield, soil organic C stock, soil N_2O emissions, mineral N under various input and tillage systems was evaluated at the field scale. In addition, modeled crop productivity was evaluated against the regional and national crop productivity data from the Swiss Federal Statistical Office.

Following the DayCent parametrization and evaluation, the model was applied to examine the long-term effects of various management practices and their combinations on soil GHG emissions at the site and regional scales. The application of the model at the site level provided an evaluation of a wide range of management practices and their combinations as they were implemented in Swiss long term experimental trials, whereas the regional scale application evaluated selected management combinations over larger spatial domain covering all unique combinations of crop rotation, climate, and soil types across Switzerland.

At the regional scale, the following management practices and their combinations were evaluated: organic fertilization, reduced tillage and winter vetch cover cropping. Cropping systems with a typical crop-specific mineral fertilization and conventional tillage without cover cropping were set as a baseline. Two types of an organic matter addition were considered: a) litter or animal manure with high decomposability; b) partially decomposed organic material (e.g., compost). Firstly, spatial data sets on management, crop, soil (European Soil Database), and daily climate data (MeteoSwiss) representing Swiss agriculture were compiled for regional-scale modeling. Grid-level (2.2 km resolution) simulation was performed for the years 1991 to 2013, and then aggregated to the regional scale. Then the changes in soil GHG emissions and crop productivity by adopting selected practices were determined.

Modelling results at the regional scale

Soils under conventional practices were a net source of soil GHG emissions. Net soil GHG emissions were estimated to be 1.59 ± 1.25 (mean ± SD) Mg CO_2eq ha^{-1} yr^{-1} over cantons and years. There was a significant trend of declining SOC content over time at a rate of approximately -0.24 Mg C ha^{-1} yr^{-1}. Mean soil N_2O emissions varied between 1.42 and 2.13 kg N ha^{-1} yr^{-1}. The C and N_2O losses from soils were considered a major source of the net soil GHG emissions, contributing 56% and 44%, respectively, to the global warming potential.

- The use of litter or animal manures with high decomposability and partially decomposed organic fertilizers reduced soil GHG emissions from conventionally managed soils by 0.34 ± 0.38 and 1.10 ± 1.16 Mg CO_2eq ha^{-1} yr^{-1}, respectively. The emission reduction was mostly attributed to the soil organic C increases by 104 ± 92 and 259 ± 314 kg C ha^{-1} yr^{-1} relative to conventional management. In general, crop yields increased by adding organic fertilizer with high decomposability compared to conventional yields by up to 28.7%. In comparison, when organic amendments were partially decomposed, there was yield decline from -5.4% to -43.2% across the crops.
- Regardless of the type of organic fertilizer, its application with reduced tillage effectively increased the levels of soil organic C. Furthermore, the management combination of fertilization with partially decomposed organic material and reduced tillage management had the largest potential to reduce N_2O emissions. However, the changes in crop yield tended to be more variable, due to negative interactive effects with reduced tillage.
- Adopting organic fertilization combined with vetch cover cropping resulted in minor mean increases in soil organic C (36 kg C ha^{-1} yr^{-1}). The potential for reducing N_2O emissions was also limited. The use of organic fertilizers with high decomposability combined with and without cover cropping increased soil N_2O emissions compared to conventionally managed soils. On the other hand, this management combination led to the largest increases in crop yield by up to about 38.0% compared to conventional yields. In comparison, the estimated reductions in yield by the use of partially decomposed organic fertilizer alone were counter-balanced by cover cropping.

- Adopting organic fertilization combined with reduced tillage and vetch cover cropping increased the mean SOC content up to 433 kg C ha^{-1} yr^{-1}. However, the management combination of organic fertilizer with high decomposability combined with cover cropping and reduced tillage increased soil N_2O emissions by 0.16 kg N ha^{-1} yr^{-1}. On the other hand, the management combination of partially decomposed organic fertilizer combined with cover cropping and reduced tillage led to the highest GHG mitigation potential relative to the conventional management (1.77 Mg CO_2eq ha^{-1} yr^{-1}), which could offset most of GHG emissions from soils that in turn can act as GHG neutral or even net GHG sinks.

Overall, changes in N_2O emission for soils under alternative practices made relatively small contribution to the net GHG emissions compared to that of SOC changes (83-100%). Nevertheless, large spatial variability of N_2O emissions appeared to drive uncertainties associated with the net soil GHG emissions.

Modelling results at the site scale

- Reduced tillage intensities relative to conventional tillage reduced the long-term soil organic C loss and thus CO_2 emissions by up to 50% at the Changins site although this decrease was not significant. In comparison, no tillage significantly reduced long-term CO_2 emissions by 76% at the Reckenholz site. Furthermore, our results show that reduced tillage and no-tillage led to an 11% and 22% reduction in long-term soil N_2O emissions, respectively. As a result, net soil GHG emissions were reduced by 31% and by 58% due to reduced tillage and no-tillage over 30 years, respectively. Adoption of these practices was associated with a 5% reduction in the yields.
- Cover cropping did not significantly reduce long-term CO_2 emissions, although there were some trends of decreasing soil CO_2 emissions at the Reckenholz site. Vetch reduced CO_2 under conventional ploughing by 35%, and had no effect on CO_2 emissions under no-tillage management relative to no cover cropping. Mustard and phacelia mixture reduced CO_2 under conventional ploughing by up to 15%, while they increased CO_2 emissions by 12% under no-tillage management. This may be due to a slower incorporation of surface residues into the soil under no-tillage than under conventional ploughing management. Mustard and phacelia mixture cover copping did not significantly affect N_2O emissions in the long-term. Vetch significantly increased N_2O emissions by 10%, perhaps as a result of an additional N input through biological N fixation (around 7 kg ha^{-1}yr^{-1}). Cover cropping did not significantly influence net soil GHG emissions, but there was a tendency for vetch to reduce net soil GHG emissions. This suggests that biological N fixation can contribute to the mitigation potential of cover cropping. Overall, cover cropping increased yields.
- Not all the GHG mitigation options sustained modelled crop yields at the site level. Organic farming, particularly in a combination with reduced tillage, substantially reduced net soil GHG emissions, while it also decreased the yield. In contrast, composting of organic manures, reduced tillage and no tillage effectively reduced net soil GHG emissions without a noticeable reduction in the yield (i.e., up to 5%).

Implications for research

Ecosystem process-based models provide effective and robust tools to bridge data gaps, to understand and quantify soil GHG emissions responses to changes in soil management. Furthermore, these models can be used to identify and evaluate long-term effects and strengths of selected GHG mitigation options and thus support climate change strategies. DayCent is a dominant coupled soil-plant dynamic model that has been widely used to simulate the long-term ecosystem responses to changes in soil management and climate in the USA. However, its application to European cropping systems has been limited. One of the outcome of COMET-Global project is that the DayCent model has been parametrized for new crops and management practices and evaluated across a range of management practices and pedo-climatic conditions in Switzerland. The robust parametrization is expected to be applicable to other DayCent modeling studies under similar pedo-climatic conditions and enable its wider application for addressing agricultural GHG mitigation with implications for regional climate change strategies and environmental policies.

Previous research on Swiss cropping systems has been designed to investigate the influence of a range of soil management practices on agronomic performance, soil organic C and soil fertility. Yet, relatively little is known about long-term effects of these practices on soil GHG emissions. Also little is known about the biophysical potential of these management practices to affect GHG emissions from agricultural soils through their regional adoption. The results of the COMET-Global project close this research gap through identification and quantification of GHG mitigation potentials associated with the long-term adoption of a wide range of management practices at the site and regional scales. The project improved our understanding of the effects of management practices on soil GHG emissions at the longer temporal and larger spatial scales. Insights from our analyses can guide designing future GHG studies under field conditions.

The COMET-Global project is closely linked to the Climate-CAFÉ project (Climate Change Adaptability of cropping and Farming systems for Europe). Both projects have used the same Swiss long-term experimental data sets and soil and climate spatial datasets. While the management practices and their combinations were evaluated for their biophysical potential to mitigate soil GHG emissions from Swiss agricultural soils in the context of the COMET Global project, the management practices have been evaluated for their biophysical potential to adapt to climate change under 4.5 and 8.5 Representative Concentration Pathways in the context of the CLIMATE CAFÉ project. Collaborative efforts to evaluate sustainability of Swiss cropping systems offered a good opportunity to understand and quantify the effects of management practices on soil GHG emissions and yields at the site and regional scales.

Scientific publications from the COMET-Global are currently in preparation.

Practical significance

This COMET-Global project evaluated long-term effects of management practices and their combinations on soil GHG emissions from Swiss agricultural soils at the site and regional scales. The modelling results provide estimates of the GHG mitigation potentials for a broad range of management practices.

For the practices, which were evaluated across all unique combinations of crop rotation, climate, and soil types in Switzerland, i.e., at the regional scale, the mitigation potential decreased in the followed the order:

a) Application of partially decomposed organic fertilizers in combination with reduced tillage management and winter vetch cover cropping (1.77 ± 0.24 Mg CO_2eq ha^{-1} yr^{-1});

b) Application of partially decomposed organic fertilizers in combination with reduced tillage management without cover cropping (1.66 ± 0.24 Mg CO_2eq ha^{-1} yr^{-1});

c) Application of partially decomposed organic fertilizers in combination with conventional tillage management and winter vetch cover cropping (1.19 ± 0.19 Mg CO_2eq ha^{-1} yr^{-1});

d) Application of partially decomposed organic fertilizers in combination with conventional tillage management and without cover cropping (1.11 ± 0.17 Mg CO_2eq ha^{-1} yr^{-1});

e) Application of litter or animal manure with high decomposability in combination with reduced tillage management and winter vetch cover cropping (0.92 ± 0.23 Mg CO_2eq ha^{-1} yr^{-1}).

The lowest mitigation potential was associated with vetch cover cropping alone (0.07 ± 0.05 Mg CO_2eq ha^{-1} yr^{-1}), application of litter or animal manures with high decomposability alone (0.34 ± 0.10 Mg CO_2eq ha^{-1} yr^{-1}) and reduced tillage alone (0.42 ± 0.15 Mg CO_2eq ha^{-1} yr^{-1}).

Estimates of the mitigation potentials for management practices, which were evaluated only at the site level at the long-term experimental sites:

a) Application of slurry manures in combination with reduced tillage management and mustard, phacelia mixture or vetch winter cover cropping at the Reckenholz site (from 1.67 ± 0.28 to 2.00 ± 0.28 Mg CO_2eq ha^{-1} yr^{-1} depending on the cover crop species);

b) Application of slurry manures in combination with conventional tillage management and mustard, phacelia mixture or vetch winter cover cropping at the Reckenholz site (from 0.56 ± 0.28 to 0.74 ± 0.28 Mg CO_2eq ha^{-1} yr^{-1} depending on the cover crop species);

c) Application of slurry manures in combination with reduced tillage management without cover cropping at the Reckenholz site (1.78 ± 0.28 Mg CO_2eq ha^{-1} yr^{-1});

d) Application of no-tillage relative to conventional tillage at the Reckenholz site (0.8 ± 0.28 Mg CO_2eq ha^{-1} yr^{-1});

e) Application of rototiller relative to conventional tillage at the Changins site (from 0.37 ± 0.30 to 0.56 ± 0.30 Mg CO_2eq ha^{-1} yr^{-1} depending on the soil texture);

f) Application of chisel or cultivator relative to conventional tillage at the Changins site (from 0.11 ± 0.30 to 0.26 ± 0.30 Mg CO_2eq ha^{-1} yr^{-1} depending on the soil texture).

In addition to the estimates of the GHG mitigation potentials associated with management practices, the modelling results provide estimates of the management effects on crop yields. This information might promote management practices that effectively mitigate GHG emissions without a commensurate decrease in crop production.

The modelling results of the COMET Global project are relevant to farmers, land managers, extension officers and decisions makers. Furthermore, regional scale GHG estimates provide policy and decision makers with risk information to make process-based emission budgets and set up a feasible target for GHG emissions mitigation, thereby have implications for regional and national climate change mitigation strategies and environmental policies in Switzerland.

The COMET-Global system is web-based, free and accessible by anyone having an internet connection. Key attributes of the system include:

1) Use of advance methods, capability to include robustly evaluated process-based models for estimating soil organic C and soil GHG emissions (i.e., DayCent, ECOSSE, RothC). Currently the system is only hosting the DayCent ecosystem biogeochemical model. The models are run in real-time at high spatial resolution, using site-specific data on soil properties, climate and land use and management practices. The dynamic modeling capabilities for soil GHG emissions and removals has the potential to provide more accurate and locally relevant estimates of emissions, capturing the interacting effects of environmental and management variables at field-scales. The spatial interface enables the use of many geographically-distributed databases that provide input to GHG calculations for specific locations and it allows the user to visually relate to the locations where the estimates are being made. Because the pan-EU databases for soils, climate and land use/management are available as default data in the system, COMET-Global is available to users in non-partner EU countries as well, but with less specificity.

2) Flexibility, so that users can select, were appropriate, the most up-to-date GHG country-specific methods and accounting procedures, emission factors, and parameters for non-soil GHG emission sources, while still retaining the option to apply a uniform set of methods and standards across all countries.

3) User-friendly design, making it possible for land managers and others, without specialized knowledge of GHG emission processes to use the system, in their native language; and

4) Capabilities to compute statistically-based uncertainty estimates, based on robust state-of-the-art methods makes the tool highly relevant for analyzing GHG mitigation outcomes related to policy or incentive programs.

The user interface is provided with multi-lingual capabilities (English, French, Spanish, German and Italian) to provide maximum convenience on the part of a multinational user community.

This indicates that the COMET-Global system provides an improved methodology for a full GHG emissions assessment from agricultural resources and thus studying the GHG mitigation at the farm scale, universally accessible to farmers and decision makers without specialized knowledge of GHG emission processes. Currently the prototype system is functional but we are in the process of seeking further funding to host the system on a publically available web-site and to have resources to pay for web-servers and at least a minimum level of maintenance and use support.

Recommendations

To all stakeholders in each of the partner's countries, we recommend using the COMET-Global system for the full GHG accounting at the scale of an individual entity before an implementation of any changes in the land use or land management.

The modeling results suggest that most of the evaluated management practices can be effective in reducing the net soil GHG emissions from Swiss agricultural soils, although not permanently, but mainly through the increase in soil organic C. Therefore, the challenges are present to deliver reduction in soil GHG emissions with the combination of alternative practices and complex crop rotation patterns that is more permanent and associated with minimum yield penalty.

The following management practices were found to substantially reduce net soil GHG emissions, while causing a reduction in the overall production: an application of partially decomposed organic fertilizers, particularly in a combination with reduced tillage. In contrast, organic farming with cover cropping, reduced tillage and no-tillage effectively reduced net soil GHG emissions without a noticeable reduction in the yield (i.e., up to 5%).

It is well known that the model estimates are uncertain. The key sources of uncertainty in the model originate from model structure, parameterization and input data (e.g., N fertilization rate, timing of management events, soil properties, climate data). The uncertainty induced by model parameters or input values can be estimated by the Monte Carlo approach, while the uncertainty related to the overall model structure (equations in the model that represent the real-world processes), imperfections in parameterization and initial values can be estimated using empirical models that quantify the deviation of the model predictions from the independent observations. The assessment of how the uncertainties in some model components translate into uncertainties in model outputs has not been accomplished within the COMET- Global project. More work should be done to characterize the impacts of key sources of uncertainty on modelled soil GHG emissions and crop yields at the site and regional scales.

Some management practices (i.e., use of various cover crops, tillage intensities, reduction in the fertilization) were evaluated only at the site scale at few experimental sites. These are not representative of all pedo-climatic conditions of Switzerland. As not only soil management but also pedo-climatic conditions control soil GHG emissions, the extent of the mitigation potential of these management practices and their combinations should be further evaluated across a range of pedo-climatic conditions at the regional scale.

Some of the management practices might exhibit a substantial potential for mitigating soil GHG emissions from Swiss agricultural soils, but they might increase GHG emissions off-site (e.g., composting or organic manures). Therefore a more comprehensive GHG assessment of Swiss cropping systems taking into account all other emissions associated with the production of fertilizers, energy use, manure storage, composting and livestock emissions is needed to be addressed in the future studies.