Report on the comparison of 3 carbon monitoring methods and on the implementation of the method (French case)

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Name of report	200328 – D05 Report on the comparison of 3 carbon monitoring methods and on the implementation of the method (French case)
Summary/brief description of report	This report corresponds to the 2020 Output n° 5: “Improved method for soil carbon monitoring (French case)”. It concerns the Work Package 2 “Developing and implementing an action plan with demand owner 2, Nataïs, Gers, France” and to the Task 2.2. in which deployment of SAFYE-CO2 soil carbon method was continued and a comparison initiated with other carbon monitoring methods. The report will present the results obtained on one farm from the Nataïs network. First, we present the study area along with the primary objective of the task. Second, we describe the carbon monitoring methods as well as their differences and similarities. Third, we present the results for each carbon monitoring method outputs. Finally, we will discuss these results with respect to their differences and similarities.
Date of report	31/12/2020

Supporting Documents: none

Report on the comparison of 3 carbon monitoring methods and on the implementation of the method (French case)

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Introduction

This Deliverable concerns the Work Package 2 “Developing and implementing an action plan with demand owner 2, Nataïs, Gers, France” and is associated to the Task 2.2. in which the deployment of the SAFY-CO2 soil carbon method was continued and a comparison initiated with other carbon monitoring methods.

Context

The Intergovernmental Panel on Climate Change (IPCC, 2018) has reiterated the need for urgent action, in order to ensure our future under climate change. To remain within the 1.5°C target, urgent action at unprecedented scales and across all sectors is required within the next 10 years. Agriculture has a major role to play to meet this target through lowering its greenhouse gas (GHG) emissions and capturing carbon dioxide (CO2) from the atmosphere and sequestering part of it in the soil. At the same time, agricultural systems need to be ready to adapt to climate change, and supply sufficient food to feed a growing world population, while preserving water, biodiversity and soil resources.

Soil carbon sequestration (SCS) represents up to 90% of the mitigation potential for the global agriculture sector (Smith et al., 2014). Based on the preservation and restoration of soil health, namely through increase and maintenance of soil organic matter, soil appears as a major solution to address the threefold challenge of climate change mitigation, adaptation to climate change and food security. SCS can contribute to reducing our net anthropogenic GHG emissions, while preserving and restoring soil health through the increase and maintenance of soil organic matter, thus contributing to enhanced production resilience and food security (Smith et al., 2014). Carbon farming includes a variety of agricultural methods aimed at sequestering atmospheric carbon into the soil.

In this context, Nataïs already supports the implementation of cover crops via a fixed bonus for the producers who grow them, as this practice as been identified as one of the most efficient for storing C. They will be the first processor to pay farmers for the reduction of their carbon footprint. Thanks to a collaboration with INRAE (CESBIO laboratory) within the frame of this project and of the Naturellement Popcorn project, we aim at quantifying the real amount of cover crop biomass produced by remote sensing so they can adjust the bonus to the farmers accordingly. Indeed, the cover crop biomass is crushed and incorporated in the soil before the sowing of the maize and this practice brings organic matter to the soil. Recently, the demand owner, Michael Ehmann, President of Nataïs (www.popcorn.fr) started adding compost on its farm (named Villeneuve) located in Bézéril (South West France, see Figure 1) with the objective of increasing SOC stocks and improve soil fertility. In this report, we will focus on the quantification of the C budgets and the effect of the management practices (cover crop, compost, crop rotations…) on the SOC stocks dynamics of the parcels of this farm.

Note that it had been requested in the Business Plan 2020 amendment that only one farm would be studied instead of three for this report, but due to an oversight in Climate KIC's process the change was not finalised. Because of the multiple lockdown in France in 2020 (caused by the COVID-19), it was considered too ambitious to collect data on several farms, therefore we requested the analysis to be limited to one farm.

Objectives of the task

The primary objective of this task is to compare three methods for monitoring soil carbon stock changes in agricultural soils at the Villeneuve farm which is part of the Nataïs network. The two first approaches

(AMG research, SIMEOS-AMG) are based on the AMG soil model requiring crop maps, mean annual climatic data, data concerning soil properties, field management and yield. Those models are focussed on the soil processes that determine Soil Organic Carbon (SOC) mineralisation.

The third method is based on the AgriCarbon-EO processing chain encompassing the SAFY-CO2 model. SAFY-CO2 is a crop model driven by remote sensing images (e.g. Sentinel 2), that requires data concerning organic amendments and straw management (no other management data needed), daily climatic data as well as crop maps. This model is focussed on the quantification of the C fluxes entering and leaving the plots. It simulates plant processes (photosynthesis, plant respiration) and soil respiration driving the CO_2 exchanges between the plots and the atmosphere. It also computes the biomass production (cash crops and cover crops) and the amount of carbon exported at harvest (cash crop). Soil CO_2 emissions (SOC mineralisation) are simulated by using a simple empirical equation function of the soil temperature. The dynamics of the SOC pools are not simulated by the model.

The results of each approach will be presented and discussed. The goal is to identify which approach or combination of approach would be best suited to quantify the C budgets at plot scale and the effect of the management practices (cover crop, compost, crop rotations…) on the SOC stocks dynamics.

Area of study

The studied farm, thereafter named "Villeneuve" is located at Bézeril (Gers Department) in South West France (see Figure 1).

Figure 1: map showing the location of the Villeneuve farm (red dot) in France.

It belongs to Michael Ehmann, President of Nataïs (www.popcorn.fr) that is a private company, today leader in the European popcorn market with 35% of the European market share (wholesale and bags). Nataïs already supports the implementation of certain virtuous practices (cover crops, conservation tillage...) via a fixed bonus for the farmers according to their practices. Our modelling exercise mainly aims at identifying the best approach for quantifying the additional carbon storage allowed by the implementation of cover crops over the Nataïs farm network in order to adjust the bonus accordingly.

The Villeneuve farm is composed of 13 parcels encompassing the Nataïs factory (see Figure 2). The cropping system is based ona popcorn maize/winterwheat/cover crop crop rotation. Three of the parcels are in agroforesterie (noted Parc_X_Agrof on the map). Each year, approximately half of the parcels are grown in pop corn maize while the other half is grown in winter wheat. Cover crops (usually sown at fall and destroyed in spring) are grown during the fallow period following winter wheat and preceding maize. The cover crops are generally a mixture of Fava Bean and Phacelia at this farm. As the cropping years start in late September (and end 365 days later) the cover crops and the pop corn maize are grown within the same cropping year whereas the winter wheat copping years, no cover crop is grown (the soil remains bare between winter wheat harvest and the beginning of the next cropping year).

Figure 2: map of the 13 parcels of the Villeneuve farm encompassing the Nataïs factory (located between Parc_8_west and Parc_8_Agrof). Three of the parcels are in agroforetery (noted Parc_X_Agrof on the map). All are characterized by a popcorn maize/winter wheat/cover crop rotation.

In this exercise, the plots concerned by agroforestry will be simulated only by the SIMEOS-AMG monitoring methods as 1) the AMG research model alone is not adapted to parcels with agroforesty for calculating trees biomass production and 2) the remote sensing products (Green Area Index dynamic maps) needed for SAFY-CO2 are disturbed by the presence of the trees (crown, shadows…) inside the parcels.

Presentation of the carbon monitoring methods

AMG research model

The AMG model was created in 1999 (Andriulo et al , 1999). It is derived from the first SOC balance model established in France by Hénin and Dupuis (1945), which has been widely used by agricultural advisors and teachers, and also by agricultural researchers until recently. The Henin-Dupuis model is one the simplest models simulating C balance in soil and is comparable to ICBM family models (Andrén and Kätterer, 1997). It considers two compartments of organic carbon (OC): fresh carbon inputs (from aerial and root crop residues and organic amendments) and the soil organic carbon (SOC).

Using this model, several authors such as Mary and Guerif (1994), Wylleman et al (1999; 2001) found that the model tends to under-estimate the actual variations of SOC in the short-term and over-estimate them in the long-term. Furthermore, the fitted values of k1 (see below) did not correspond to the estimates which can made using long-term incubation in the laboratory.

In AMG model (see Figure 3), the humified SOC pool is divided into two parts: an active compartment C (Ca) and a stable one (Cs) which is considered totally inert on the short and mid terms (i.e. that its turnover time is millenary). The active pool is the only pool fed by fresh C inputs and affected by the annual mineralization (outputs).

This transformation has signed the creation of AMG which takes into account the generally accepted result that the humified SOC pool is not homogeneous.

The current version of AMG model has three compartments of OC (fresh exogenous OC, active SOC and stable SOC)). It has three main parameters:

k1 = “humification coefficient”, *i.e*. the conversion efficiency of the fresh carbon inputs into humified SOC;

k2 = annual rate of SOC mineralization.

Cs/Co = initial proportion of stable carbon (Co = initial SOC content)

k1 is supposed to depend only on the nature of the fresh organic inputs, whereas k2 is supposed to depend on the soil (clay and lime contents), soil tillage (type and depth) and the meteorological conditions (mean air temperature and water balance).

Compared to Henin-Dupuis model, the predictive value of the AMG model is significantly improved. Compared to more complex models such as Century, it remains a simple model, well adapted for developing decision support systems (see below with Simeos-AMG), and which may perform as well for applied purposes. AMG concepts are embedded in the crop model STICS which simulates C and N balances at a daily time step (Brisson et al, 2008).

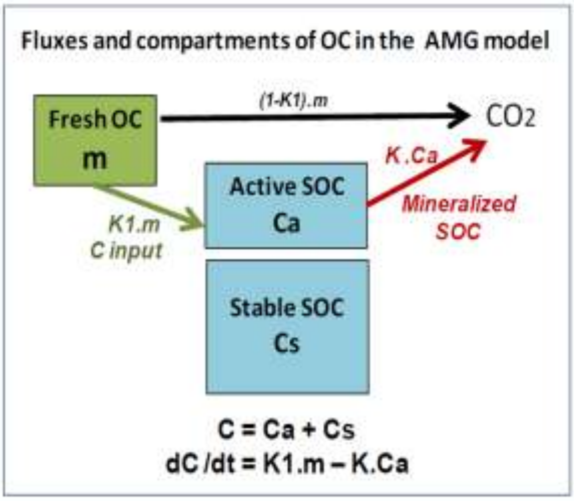


Figure 3: Schematic representation of the AMG model

The requested input data are the soil contents: initial OC, clay, limestone, pebble content, bulk density; sampling depth for soil analysis; soil tillage type (plowing, no till) and depth for each year; average annual temperature and water balance (precipitation + irrigation – potential evapotranspiration); crops sequence and crop yields; residues management (return or removal); nature, biomass and frequency of catch crops and organic amendments. The output data are:

- SOC stocks over the "depth of topsoil" defined as the larger value between sampling depth of soil analysis and deepest tillage operation during the rotation,

- SOC content and concentration of the deepest tilled layer during the rotation (assuming that tillage homogenizes the concentration of organic materials down to this depth).

The model runs on a yearly basis and it accounts for the real annual management practices at plot level (e.g. organic amendments).

To estimate the biomass of cash crops incorporated into the soil, the yield (provided by the farmer) is first converted into aerial biomass via a harvest index (crop specific). Then the estimated total biomass is estimated by using an allometric relationship between aerial biomass and root biomass (Baret et al. 2002). Aboveground and belowground biomasses are then summed to calculate the total biomass. Finally the difference between total biomass and harvest correspond to the Fresh OC term (fresh C inputs in the soil) shown in Figure 3.

The biomass of cover crops returned to the soil is estimated for each plot via a reference value fixed nationally for a given type of cover crop (e.g. a single value of biomass for all Fava bean cover crops in France).

The decision support tool SIMEOS-AMG

The SIMEOS-AMG tool was set up in the course of a regional research-development project on Soil Organic matter management in Picardy region (northern France). It implements the AMG model to perform SIMulations of Soil Organic Status at the field scale and on the long term.

The simulations are performed on the basis of scenarios (not the real crop rotations or field managements) taking into account the soil type, the local climate and the cropping system. In contrast with AMG-Research, the cropping system is supposed to remain the same over the duration of the simulation (idealised rotation, mean management practices such as mean organic amendments). The input data and the parameters required for the calculations are either readily available on the farm and entered by the user, or found in various catalogues (soils, regional climates, crops and organic products) integrated in the tool and mobilized through drop-down menus or by consulting reference tables.

The advantage of this tool is that it allows the farmers to enter their own data in the tool through a dedicated web portal. The disadvantage is that the tool estimates the C budgets based on idealized crop rotations and mean management practices over the simulation period that is minimum 10 years (but up to 100 years).

SIMEOS-AMG was developed as an individual advising tool instrument for the farmer and an educational support for teachers in agricultural schools (see Figure 4). The more classical implementation for advisory or educational support can be described as follows:

- Starting by actual cases known on the farm and declining them in number of theoretical variants, the simulations allow for understanding how different factors (agricultural practices or natural conditions) can influence soil organic evolution in the long term.
- Simulations are then used to assess the impact of current practices in different fields of the farm. The diagnosis is mainly based on the dynamics revealed by the evolution curves (increase, decrease or stagnation) and on what the farmer knows about the behaviour of the soil examined (crusting frequent or not in loamy soils; difficulty in tillage in clay soils; water infiltration problems...).

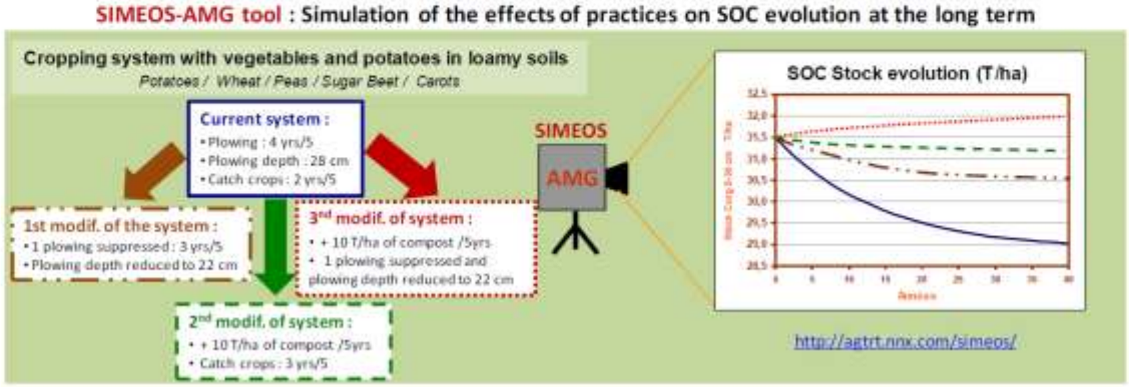


Figure 4: Examples of application of the Simeos-AMG tool for decision support.

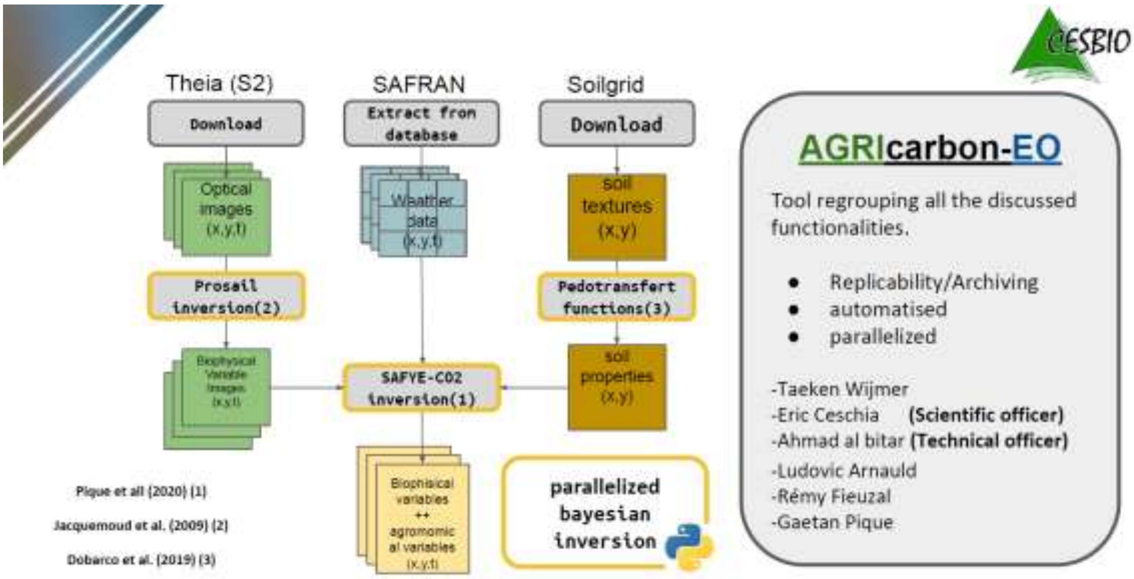
Finally, the farmer can see the long term effect of alternative practices compared to those he currently applies. The examination of costs, physical constraints or work organization associated with various technical options can accompany these comparisons and help establish the expected advice, in adapting it to either the context of operation, the means and objectives of the farmer.

SIMEOS-AMG can also be used to establish quantitative prescriptions. It can be used for instance to determine the rate of exportation of cereal straw, without taking a risk for the soil organic status on the long term. The expected output is a quantitative prescription, which implies to quantify the consequences of changes in SOC content on agronomical properties and behaviour of the soil. Thus, not only the dynamics of evolution revealed by the simulation curves, but also the levels of SOC attained at the end of the simulation period, has to be taken into account. This principle is applied to several current studies in France where SOC balances or GHG balances with integration of SOC variations are to be performed at a territory scale.

AgriCarbon-EO

In this study, we quantify the components of the carbon budget at high resolution and we analyse the effect of cover crops. Computations are based on the newly developed end to end AgriCarbon-EO processing chain that encompasses the SAFY-CO2 model.

The AgriCarbon-EO processing chain (see Figure 5) allows to calculate the components of the carbon budgets (yield, biomass, CO_2 fluxes) at plot scale or at 10-20m resolution by assimilating Sentinel 2 satellite data. The assimilation scheme is based on a Bayesian approach which provides dynamic maps of biogeophysical variables (Green Area Index, GAI; Fraction Cover, Fcover) with their associated uncertainties. Uncertainties are essential when determining the carbon budgets as they can impact negatively the bonus paid to the farmers for storing additional C with the cover crops. The biogeophysical variables are derived from the Sentinel-2 surface reflectance by inverting the PROSAIL model (Jacquemoud et al. 2009). These are then assimilated (as well as their uncertainties) into the SAFY_CO2 model (Pique et al. 2020 a and 2020 b) to determine the components of the carbon budgets at pixel scale for each plot (and their associated uncertainties).



Tool regrouping all the discussed functionalities.

- Replicability/Archiving
- automatised
- parallelized

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-Eric Ceschia **(Scientific officer)**
-Ahmad al bitar **(Technical officer)**
-Ludovic Arnauld
-Rémy Fieuzal
-Gaetan Pique

Figure 5: Schematic representation of the AgriCarbon-EO processing chains

The daily time steps SAFYE-CO2 model (see Figure 6) simulates the temporal evolutions of vegetation variables (GAI, biomass and yield) and of the CO_2 (photosynthesis, plant and soil respiration) and water (evapotranspiration) fluxes using climate input variables (precipitations, air temperature and global incoming radiation). The parameters of the model are either fixed (extracted from literature or from in-situ measurements) or variable and calibrated based on the comparison between GAI observed by satellite and GAI simulated by the model. The parameters (fixed and calibrated) are crop specific and fully detailed in Pique et al. (2020a) and Pique et al. (2020b) for winter wheat and sunflower, respectively. The parameters for maize haven't been published yet. The parametrisation for cover crops is generic and are presented in Pique et al. (2020a). Concerning the calibrated parameters, on each simulated field/pixel and for each vegetation cycle independently, the values of the 8 calibrated parameters (relative to phenology and light use efficiency) are determined by minimizing the quadratic difference between the simulated and satellite derived GAI through a Bayesian approach and the use of lookup tables. This step allows the model to reproduce all types of vegetation developments observed by satellites (cash crops and cover crops) on the considered fields and to calculate the uncertainties associated to each simulated variable.

In SAFY-CO2, the photosynthesis (GPP) is estimated as a function of the incoming global radiation (Rg), the climatic efficiency (εc), the fraction of incoming radiation (APAR) absorbed by the plant (fAPAR), a temperature stress function (fT), the effective efficiency of the conversion of absorbed radiation to fixed CO2 through plant photosynthesis (fELUE), and a multiplicative coefficient (sR10), which takes into account the decline in canopy photosynthetic capacity during the senescence phase (see Pique et al. 2020a). The total biomass production (NPP) is then derived from the difference between the GPP and the plant respiration (Ra), which was separated into two components: maintenance respiration (Rm) and growth respiration (Rgr) (McCree, 1974). Then, the total NPP is divided into root (NPPr) and aboveground (NPPa) components, estimated by considering a root-to-shoot ratio (RtS) in accordance with the method proposed by Baret et al., (1992).

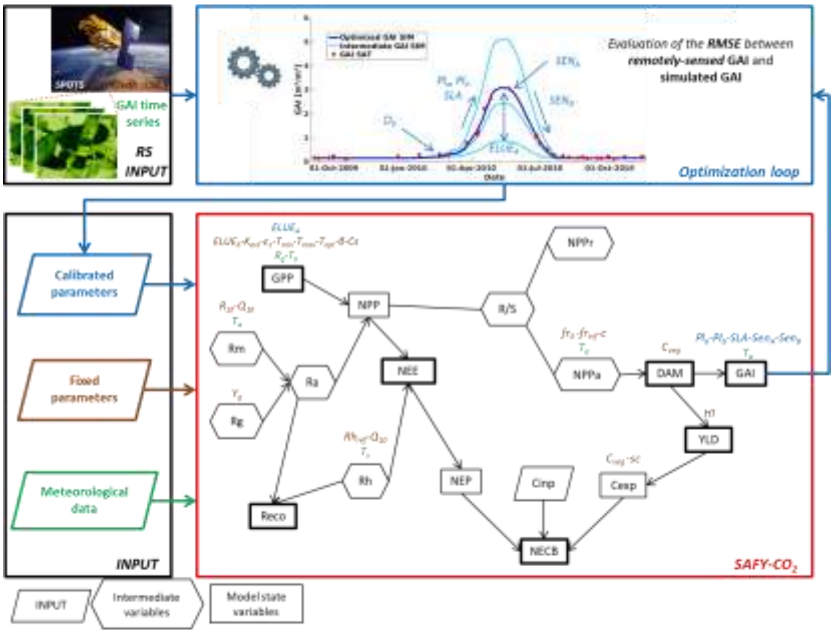

Figure 5: Schematic representation of the assimilation procedure of high resolution satellite optical images for the calibration of the agro-meteorological model SAFY-CO2, which estimates the crop biomass and the components of the net annual CO_2 fluxes (GPP for photosynthesis; R_{ECO} for ecosystem respiration, i.e. the sum of plant and soil respiration; NEE for the net ecosystem exchange that is the sum of GPP and R_{ECO}) to derive the carbon budgets (NECB) over a cropping season.

Finally, the net daily CO_2 flux (NEE) is calculated as the difference between the NPP and the carbon losses due to soil respiration (Rh). Rh is calculated using a Q_{10} first-order exponential equation depending on soil temperature (Delogu, 2013).

Note that SAFY-CO2 automatically detects the presence of cover crops and calculates their biomass incorporated in the soil at destruction as well as the additional C incorporated in the soil. SAFY-CO2 does not allow to simulate the carbon budget on plots with agroforestry.

Results

AMG research

In this section, we present the results of the AMG research model. Figures 6 and 7 show the carbon budgets estimates for each plot of the Villeneuve farm for the 2018 and 2019 cropping years, respectively. Negative values correspond to SOC losses in the 0-30 cm layer while positive values show SOC storage. The years correspond to when the cash crop was harvested. On both figures, all the maize plots, preceded by cover crops at fall, store SOC. On average, they stored 0,56 ± 0,15 T C.ha^{-1} and 1,16 ± 0,19 T C.ha^{-1} in 2018 and 2019, respectively. Surprisingly, in 2019 the maize parcels stored closed to twice the amount of SOC compared to 2018.

As cover crop biomass inputs are the same for all parcels and all years in AMG for a given cover crop specie (or melange), cover crops cannot explain this differences in C budget between the years. This difference in carbon budgets between years for the maize parcels is explained by the larger inputs of organic amendments in 2019 compared to 2018 (equivalent to 0,80 and 0,34, T C.ha^{-1} on average, respectively).

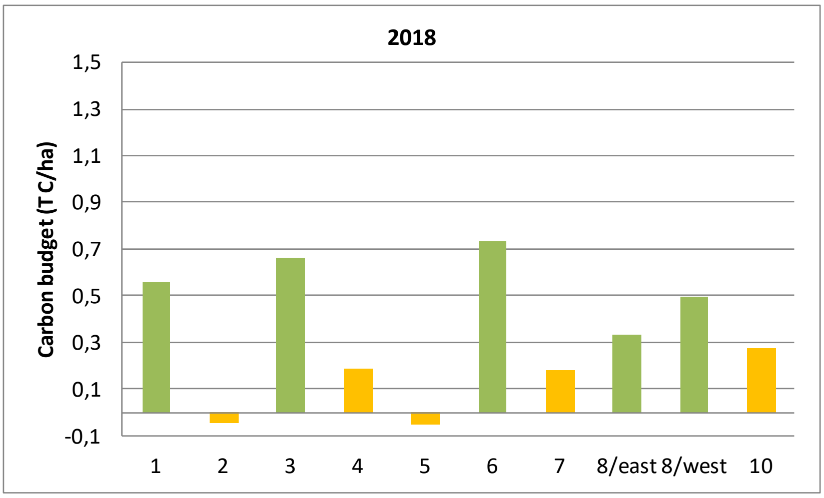

Figure 6: Carbon budgets of the Villeneuve's parcels in 2018. Green bars represent maize fields while yellow bars represent winter wheat fields.

For the winter wheat parcels, some plots lost SOC in 2018 (up to 0,05 T C.ha^{-1}) while others stored SOC (up to 0,27 T C.ha^{-1}). On average, winter wheat parcels stored 0,11 ± 0,14 T C.ha^{-1} and 0,39 ± 0,16 T C.ha^{-1} in 2018 and 2019, respectively. Here again, in 2019 the winter wheat parcels stored closed to twice the amount of SOC compared to 2018. For the winter wheat parcels, this difference cannot be explained by differences in organic amendments or cover crops as none occurred during the winter wheat cropping years. The differences comes from larger cash crop residues input in 2019 compared to 2018 (respectively, 1,25 and 0,78 T C ha^{-1}).

The results found with AMG research for the winter wheat plots in 2018 are somewhat surprising as the scientific literature shows that plots cultivated with winter wheat are usually close to neutral or storing C in our area when straws are buried (Béziat et al. 2009). However, Anthony et al (2004) and Ceschia et al. (2010) found that winter wheat plots could act either as C sources or C sinks in Europe.

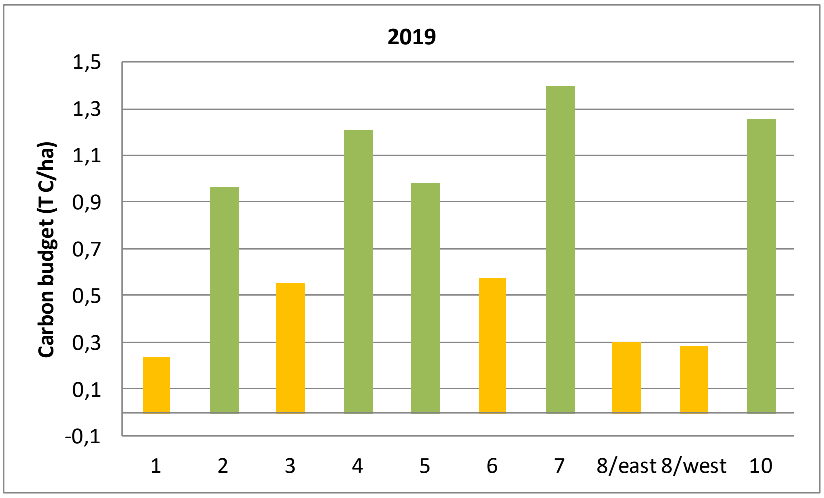

Figure 7: Carbon budgets of the Villeneuve's parcels in 2019. Green bars represent maize fields while yellow bars represent winter wheat fields.

SIMEOS-AMG

In this section, we present the results of the SIMEOS-AMG model. Figure 8 shows the SOC stock changes for each plot of the Villeneuve farm over 100 years. Negative values correspond to SOC losses in the 0-30 cm layer while positive values show SOC storage. In this exercise, the SOC dynamics for all parcels including the ones in agroforestery are shown.

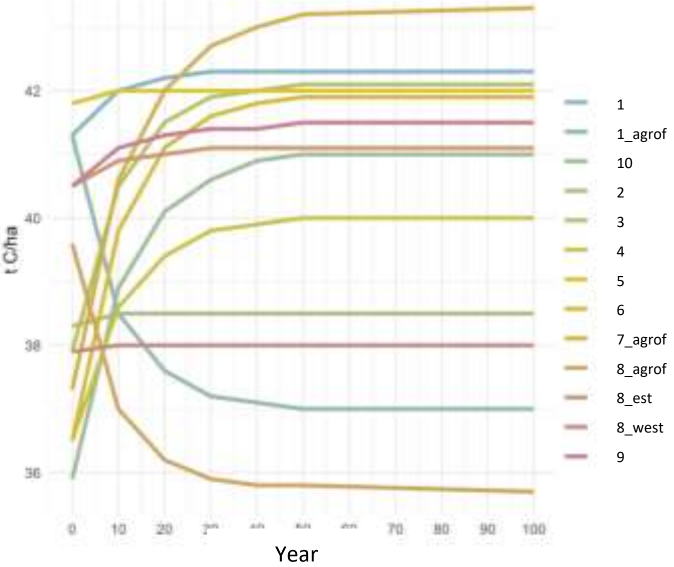

Figure 8: Dynamics of SOC stocks (t C.ha^{-1}) for each parcel of the Villeneuve farm over 100 years (2017-2117). Each colour line corresponds to a different parcel.

The results show that on most parcels there is a strong SOC dynamic with a new equilibrium reached after 50 years. Two of the parcels in agroforestry loose carbon, two parcels without agroforestry have rather stabile SOC stocks whiles all others increase their SOC stocks. It seems surprising that plots with similar management (e.g. with or without agroforestry) have so contrasted SOC dynamics. For instance, we could have expected that all parcels without agroforestery had stored or lost C. In fact, those plots had contrasted managements over the recent years that may not be representative of the mean long term management. As a consequence, SIMEOS-AMG that considered those short term contrasted managements to build its idealised crop rotations and managements may have accentuate the long term SOC dynamics.

AgriCarbon-EO

The AgriCarbon-EO processing chain was used to run the SAFY-CO2 model at pixel level (10m) all over the Villeneuve farm parcels. In this exercise, we ran run the model over the two cropping years 2016-2017 and 2017-2018. Figure 9 shows an example of simulation for one pixel of the farm corresponding to a parcel in which winter wheat was grown between November 2016 and July 2017 (harvested), followed by 1) a cover crop sown in October and destroyed in April and 2) a pop corn maize sown in may and harvested in October. The LAI (leaf area index in m^2 of green tissues per m^2 of soil) dynamics modelled by SAFY-CO2 matches well with the LAI dynamics derived from the satellite images, with some underestimation during the cover crop development. This underestimation is caused by 1) a long period without satellite acquisition during winter caused by cloud coverage and 2) the high uncertainty of the LAI data during winter because of the quality of the images and the heterogeneity of the cover crops.

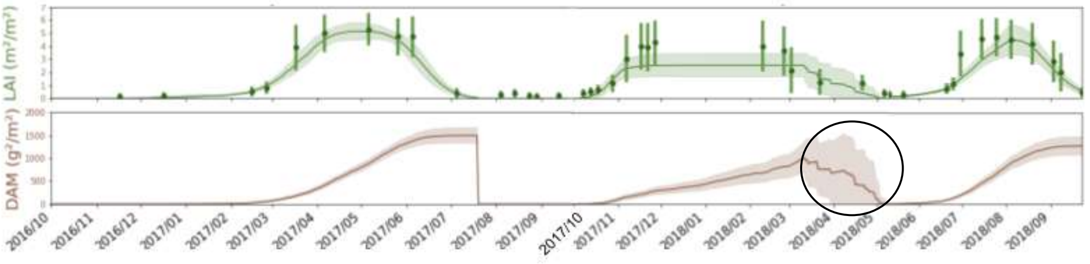

Figure 8: Dynamics of the Leaf area index (LAI; top) and Dry Aboveground bioMass (DAM; bottom) for one pixel of the Villeneuve farm between fall 2016 and fall 2018. Green dots are LAI estimated from satellite and their uncertainties (vertical bars), the green line and envelope are, respectively, the LAI simulated by the model and its uncertainty. The brown line and envelope are, respectively the DAM simulated by the model and its uncertainty.

The simulated aboveground biomass has a realistic behaviour and intensity except at the end of the cover crop period when the biomass decreases. This is in fact and artefact of the modelling process that considers during the Bayesian calibration of the phenological parameters of the model (based on a look table) some plots in the neighbourhood where cover crops have already been destroyed while other are not yet. This artefact is removed during the post processing of the simulation.

The AgriCarbon-EO processing chain is also able to produce 10 m resolution maps at the farm levels of all the intermediate variables allowing to calculate the total cash crop and cover crop biomass (below and aboveground), as well as the yields and the CO_2 fluxes (photosynthesis, plant and soil respiration) for a given cropping year. When provided with data on organic amendments, C budget maps can be calculated too.

Figure 9 shows the cover crop final aboveground biomass map over the Villeneuve farm in spring 2018 (before destruction) as well as the associated uncertainty map (Figure 10). It reveals strong intra and inter parcels variability. Most of this intra-parcels variability is associated to topography and spatial variations in soil properties (soil depth, soil texture, soil humidity…). Such a map shows how important it is to account for spatial variability in cover crop development in order to accurately estimate the C inputs in the soil.

Figure 9: Map of the cover crop final aboveground biomass in spring 2018 (before destruction) on the parcels where popcorn maize is about to be grown. Numbers are in g of dry biomass.m^{-2}.

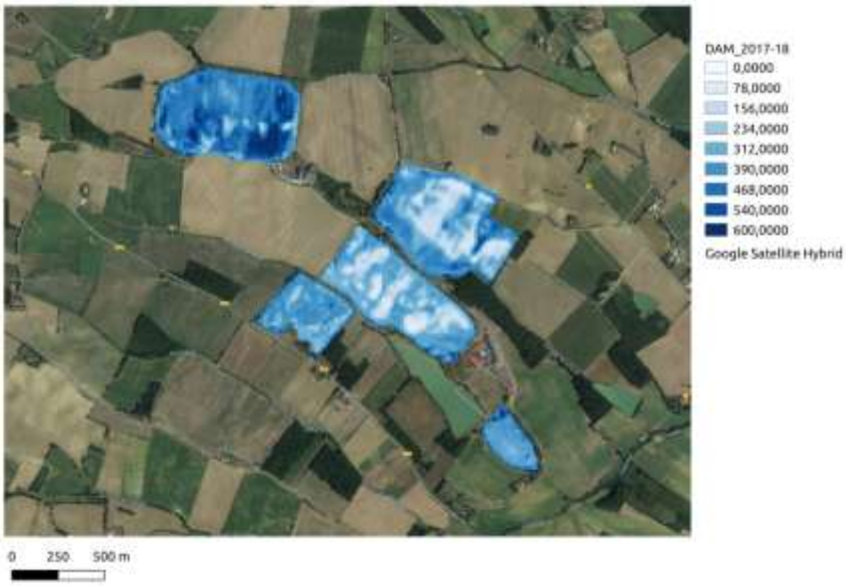

Figure 10: Map of the cover crop final aboveground biomass in spring 2018 (before destruction) on the parcels where popcorn maize is about to be grown. Numbers are in g of dry biomass.m^{-2}.

Figure 10 shows that the higher uncertainties are not necessarily where cover crops are more (or less) developed. One reason is that during the LAI inversion process by the PROSAIL radiative transfer model, some areas of the image may be affected by poor cloud detections. Also the uncertainty could be reduced by considering cover crop specific leaf/stand parameters in the PROSAIL model while currently generic vegetation parameters are used.

Figure 11 shows the SOC stock changes simulated over farm for the 2017-2018 cropping year. Here negative values represent a SOC increase while positive values show SOC losses. Numbers are in g C.m^{-2}. In this exercise, we considered, as in Justes et al. (2009), that 68% of the fresh organic C inputs in the soil (cover crop total biomass, compost) would be decomposed during the cropping year, meaning that only 23% of the fresh organic C inputs would remain in the soil. This percentage for compost is probably overestimated and it will be refined based on data from the literature. However as it represents a small amount of C brought to the plots (per m^2), the uncertainty on its mineralisation has very limited impact on the C budgets estimates.

This map shows high intra and inter parcels spatial variability in SOC stock changes over the cropping year. The greenish parcels, tending to store C, correspond to the parcels that were grown with cover crops/pop corn maize during the cropping year. The yellowish ones, loosing C, correspond to parcels that were grown with winter wheat and left in bare soil after harvest till the end of the cropping year.

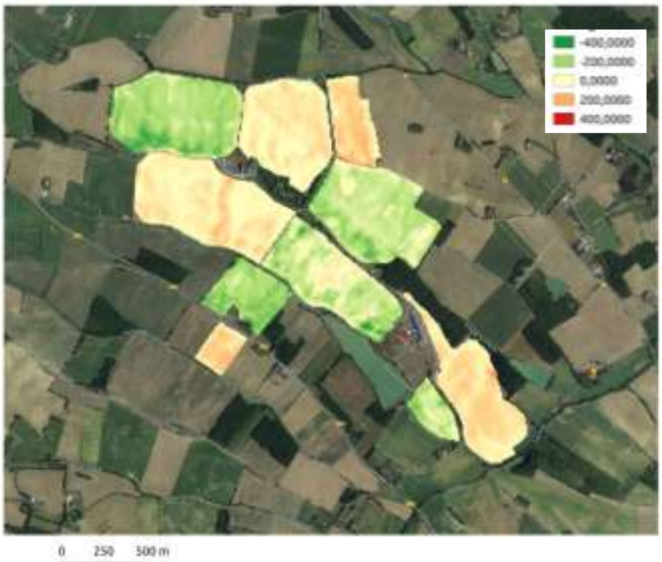

Figure 11: High resolution map of the SOC stock changes at the Villeneuve farm for the 2017-2018 cropping year. Numbers are in g C.m^{-2}. Negative values mean SOC increase, positive values mean SOC losses.

Intercomparison of the results obtained with the carbon monitoring methods

It is difficult to compare SIMEOS-AMG with the two other approaches as the crop rotations and managements of the parcels are idealised while AMG-research and AgriCarbon-EO consider the real crop rotation and management practices. Also the simulations of SIMEOS-AMG are performed over several decades while for the two other models, simulations are done on a yearly basis. SIMEOS-AMG is well suited for analysing the effect of management practices or changes in management practices on the medium/long term, while AMG research and AgriCarbon-EO are well suited for short term modelling. As a conclusion, we will only compare the outputs of AMG-research and of AgriCarbon-EO in this section.

Table 1: comparison of the variables common to AMG research and AgriCarbon-EO that account in the calculation of the SOC stock changes for the parcels of the Villeneuve farm for the cropping year 2017-2018. Numbers are in t C.ha^{-1}. Positive numbers are for SOC increases, negative numbers are for SOC losses.

		AMG research			AgriCarbon-EO		
Parcel	**Cash crop in 2018**	**Cash crop residues**	**Cover crop residues**	**SOC stock change**	**Cash crop residues**	**Cover crop residues**	**SOC stock change**
1	Maize	0,95	0,55	1,01	4,67	7,50	2,05
2	Winter wheat	0,66	0,00	-0,02	5,42	0,00	-0,71
3	Maize	0,96	0,55	1,12	4,62	6,90	1,83
4	Winter wheat	0,85	0,00	0,21	5,15	0,00	0,32
5	Winter wheat	0,73	0,00	-0,02	4,90	0,00	-0,43
6	Maize	0,97	0,55	1,19	4,60	5,06	1,24
7	Winter wheat	0,77	0,00	0,20	4,12	0,00	0,41
8/east	Maize	0,72	0,55	0,79	4,14	6,85	1,28
8/west	Maize	0,97	0,55	0,94	4,51	4,74	1,00
10	Winter wheat	0,90	0,00	0,29	4,93	0,00	0,38
Mean	**Maize**	**0,91**	**0,55**	**1,01**	**4,51**	**6,21**	**1,48**
Mean	**Winter wheat**	**0,78**	**0,00**	**0,13**	**4,90**	**0,00**	**-0,01**
STD	**Maize**	**0,11**	**0,00**	**0,16**	**0,21**	**1,23**	**0,44**
STD	**Winter wheat**	**0,10**	**0,00**	**0,14**	**0,49**	**0,00**	**0,53**

Table 1 shows that cash crop residues estimated with AgriCarbon-EO are higher than with AMG research. Considering that only grain is harvested, the cash crop residues estimated with AMG research seem very low but they appear to be quite realistic with AgriCarbon-EO considering the field data acquired at the nearby experimental FR-Auradé and FR-Lamasquère ICOS sites managed by the CESBIO. Also the cover crop residues are very low in AMG research compared to AgriCarbon-EO.

As a consequence, the ranges in SOC stock changes simulated by AgriCarbon-EO are larger than with AMG research, but there is a good correlation between both models as shown in Figure 12.

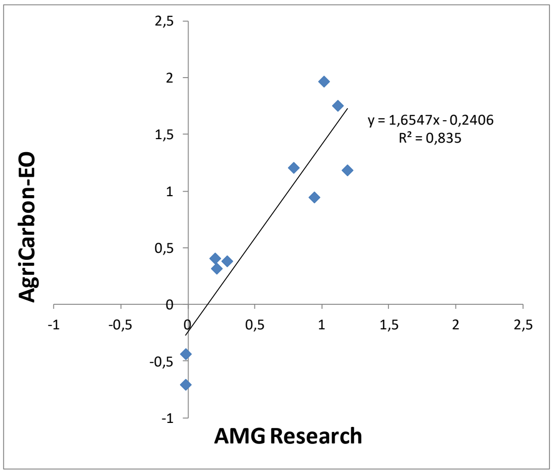

Figure 12: comparison of the SOC stock changes (tC.ha^{-1}) between AMG research and AgriCarbon-EO for the parcels of the Villeneuve farm for the 2017-2018 cropping year.

Conclusion

The three carbon monitoring tools we presented were developed in different contexts/objectives and for different purposes. SIMEOS-AMG was developed as an individual advising tool instrument for the farmer and an educational support for teachers in agricultural schools. It is particularly well suited for analysing the effect of management changes on the SOC stocks at medium long term. AMG research was developed based on long term trials were SOC stocks were followed for contrasted management practices. The SAFY-CO2 model was developed in the perspective of simulating the CO_2 fluxes and C budget components of croplands are large scale thanks to remote sensing. All have their advantages and their drawbacks.

In SAFY-CO2, the processes simulating SOC mineralisation are simplistic and there is no soil module to analyse SOC pools dynamics. On the other hand, it is well suited for monitoring the vegetation development and its spatial variability. AMG research has a soil module that analyses SOC pools dynamics but lack for spatialized information concerning C inputs in the soil through vegetation development. In the next step, our objective is therefore to couple both approach in order to benefit from the advantages from both original models.

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