14-16 November 2023 – Latresne (33)

XIIIth STICS users seminar

BOOK OF ABSTRACTS

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Latresne (33)

13-16 November 2023

Scientific committee

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Mollier Alain – INRAE/ISPA

Saint-Cast Clément – INRAE/EGFV

Seghouani Mounir – INRAE/ISPA

Vivin Philippe – INRAE/EGFV

Monday 13th november 2023

15:30-18:00	Welcome and registration	Aerocampus reception
19:00-20:00	Dinner self-service	

Tuesday 14th november 2023

07:00	Breakfast	Aerocampus
08:30	Welcome and coffee	Amphi
08:45	Seminar opening	
	Session 1 (Durand JL & Mollier A)	
09:00	Head of the AgroEcoSystem scientific division – Nesme T (visio) Deputy Director of Persyst Department of CIRAD – Justes E President of the Inrae Nouvelle-Aquitaine-Bordeaux center – Lavialle O President of the Inrae Nouvelle-Aquitaine-Poitier center – Escobar Gutiérrez A Bordeaux Sciences Agro – Ellies M-P/Henaff M Aérocampus director – Guitard C	
10:00	News on the work and governance of the STICS Project Team	
11:00	Coffee break	
11h30	Keynote : «"Is there Scope for Dynamic Crop Simulation Models in an AI World? – A View From DSSAT"» - Gerrit Hoogenboom	
	Photo	
12:30	Buffet	Rafale

	Session 2 - New formalisms, configuration and evaluations of STICS (Leonard J, Raynal H, Dumont B)	Amphi
14:00	SticsRpacks: R packages for STICS, where are we? - Buis S – Lecharpentier P	
14:20	Development, deployment and execution of simulation workflows to study the impact of climate change on dairy farms – Chabrier P	
14:40	STICS ability to simulate long-term soil organic matter dynamics in crop-grassland rotations – Graux AI	
15:00	Modelling albedo and the energy budget using the STICS soil-crop model – Application to two Sub-Saharan sites – Diop S	
15:20	Using STICS under agrivoltaic shading conditions: How to consider the impact of panels on canopy and organs temperature? - Vernier J	
15:40	**Flash presentation of posters** (9 x 2′)	
16:00	Coffee break	
16:30	Improvement of grapevine yield simulation in Champagne with the STICS model – Strullu L	
16:50	ISOP V10. Mise à jour du dispositif d'Information et de Suivi Objectif des Prairies (ISOP ; INRAE - Météo-France – MASA) – Durand JL	
17:10	AgMIP calibration: where are we and what are the results with the STICS model? - Buis S	
17:30	Discussion	
18:00	**Poster session**	
18:30	Guided tour AEROCAMPUS AQUITAINE	Hangar
20:30	Dinner cocktail	Rafale

Wednesday 15h november 2023

07:00	Breakfast	Aerocampus
08:30	Welcome and coffee	Amphi
	Session 3 - Modeling of cropping systems and biogeochemical cycles to support the agroecological transition (Louarn G)	
08:45	Simulation of long-term water, nitrogen and carbon dynamics for contrasted arable cropping systems with the STICS model – Ferchaud F	
09:05	Using a long-term experiment with a wide range of management practices to challenge N2O emission modelling with the STICS model – Belleville P	
09:25	Predicting the short- and long- term effects of recycling organic wastes in cropping systems with the PROLEG tool – Levavasseur F	
09:45	Estimating CO2 fluxes (GPP, RECO, NEE) of diversified crop rotations from STICS outputs – Delandmeter M	
10:05	Coffee break	
10:30	Conceptualization, formalisms and first evaluations of a phosphorus module for the STICS soil-crop model – Seghouani M	
10:50	Impact of cover crops on N mineral fertilization and consequences for agro-environmental performances of maize monocrop in climate change context – Willaume M	
11:10	Life cycle assessment of Quebec pig and poultry feedstuffs for the production of eco-friendly diets using the STICS model – Levraud M	
11:30	Discussion	
12:00	**Poster session**	
12:30	Buffet	Rafale

	Session 4 - Cropping systems and climate change (Garcia de Cortazar Atauri I, Combe D)	Amphi
14:00	Adapting STICS-MILA crop model to Yellow Rust of Winter Wheat : from calibration to simulation of climate change impacts – Vidal T	
14:20	Study of CO2 and temperature effects on wheat plant growth with the STICS crop model - Gawinowski M	
14:40	Evolution under climate change of the resilience of the services provided by the cultivated areas of the Pays de Fougères – Graux AI	
15:00	Spring barley yield and potential northward expansion under climate change in Canada – Jego G	
15:20	Modeling agroecological intensification in the tropics with the Stics model – lessons learned and way forward – Couedel A	
15:40	Coffee break	
16:10	Potential production of energy cover crop in France: consequences on food crop production and environmental impacts based on scenarios simulation at high resolution – Launay C/Raynal H	
16:30	Increasing soybean production in Europe: impact on cropping systems and environment – Constantin J	
16:50	Discussion	
17:30	**Dominique Ripoche-Wachter**	
18:30	**Wine Casino**	Hangar
20:00	**Gala dinner**	Castle

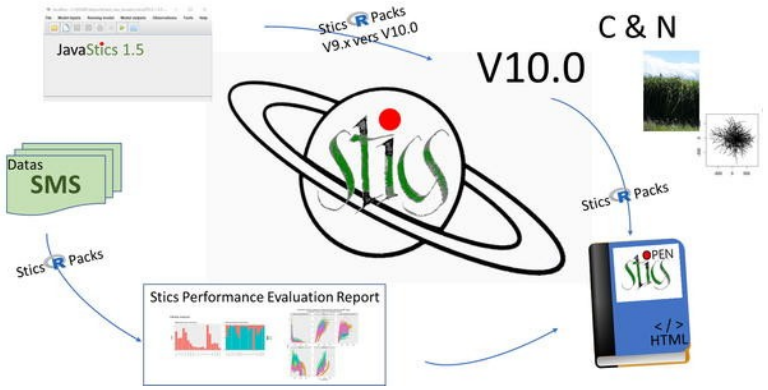
Tuesday 16h november 2023

07:00	Breakfast	Aerocampus
08:30	Welcome and coffee	Amphi
	Session 5 - Intercropping (Saint-Cast C, Vivin P, Launay M)	
08:45	Modeling key interactions in bi-specific intercropping systems: enhancing the STICS soil-crop model for sustainable agriculture – Justes E & Lecharpentier P	
09:20	Intercropping cereals and legumes to stabilise yield in the tropics: evaluation of the STICS soil-crop model to simulate bi-specific intercrops – de Freitas M	
09:40	The first calibration and evaluation of the STICS soil-crop model on chickpea-based intercropping system under Mediterranean conditions – Seghouani M	
10:00	Discussion	
10:15	Coffee break – Poster Session	
10:45	**General assembly and conclusion**	
12:30	Buffet	Rafale
14:00	**End of the XIIIth STICS users seminar**	

Content

Session 1

News on the work and governance of the STICS Project Team



Keynote : «"Is there scope for dynamic crop simulation models in an AI world? – A view from DSSAT"»

Gerrit Hoogenboom[1]

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Keywords: Crop simulation model; decision support system; CROPGRO, CERES, SUBSTOR, CANEGRO, NWHEAT, SAMUCA, MANIHOT, AROID, CROPSIM; Cropping System Model (CSM)

Introduction

There has been a significant focus on Artificial Intelligence (AI) in media, private industry, academics, and many other sectors. For instance, the University of Florida wants to become the number one institution in the USA with respect to AI education, learning, outreach, and research. To facilitate this effort, the University of Florida has invested in significant hardware upgrades of the supercomputer, called HiPerGator (https://www.rc.ufl.edu/about/hipergator/), through a donation provided by NVDIA. In addition, the University of Florida has allocated special funding to hire more than 100 new faculty for not only computer, software, and information engineering, but for all disciplines across the entire university.

There are also ample examples in science about the increased emphasis on AI. During the 2023 American Society of Agronomy–Crop Science Society of America–Soil Science Society of America annual meeting (https://www.acsmeetings.org/), there were many papers presented that included an AI component for a range of applications in agriculture. AI was also the focus during a recent plant breeding conference with emphasis on Genotype * Environment * Management interactions for yield predictions

(https://www.plantsuccess.org/event/genotype-by-environment-by-management-gxexm-symposium-ii/) .

Although AI can play an important role in agriculture, there is significant concern about using AI solely for yield prediction. With the significant improvement of computational power, more data can be used for machine learning for yield prediction. However, the outcome is limited by the data that are available for training and evaluation of the AI model. Unless one has significant agricultural domain expertise, there is a high risk of misinterpretation and misapplication of these AI models, especially for decision support and policy setting. This has been evident in various presentations at scientific meetings as well as recent publications that basically used AI to determine the covariates, rather than experts. One example that was presented showed that Latitude and Longitude can be used solely for yield prediction.

Crop Modeling Community

The crop modeling community has a very long history of more than 40 years in the development of dynamic equations for the prediction of crop growth, development, and yield as a function of daily weather conditions, local soil characteristics, genetics, and crop management. These models, including the DSSAT crop models, STICS, APSIM, and others, are based on sound science that has been conducted across multiple disciplines within agriculture such as soil physics, soil chemistry, crop physiology, agronomy, and many others. These models are also continuously being improved as more scientific information becomes available such as the response to CO2 under high temperature conditions or the prediction of Greenhouse Gas Emissions.

DSSAT

The crop models of the Decision Support System for Agrotechnology Transfer (DSSAT; www.DSSAT.net) originated in the late 1970s to address specific topics in agriculture, such as irrigation management for soybean and peanut or yield forecasting for wheat. Through the International Benchmark Sites Network for Agrotechnology Transfer (IBSNAT) Project, these models were incorporated into the DSSAT platform that includes not only the individual crop simulation models but also tools and utilities for data preparation, application programs for analysis of simulation outputs, and example data files based on real experiments (IBSNAT, 1993). The individual crop models have been combined into one comprehensive model called the Cropping System Model (CSM) to be able to address the simulation of cropping systems (Jones et al., 2003). Although the IBSNAT Project was funded for only 10 years by the US Agency for International Development (USAID), the development and availability of DSSAT has continued.

The success of DSSAT is solely based on the crop modeling community as funding for maintenance support of DSSAT has been very limited. There has been a significant interest in the use and application of crop simulation models across the globe that has supported the motivation to continue with the improvement and advancement of DSSAT. These crop modeling applications include irrigation management, fertilizer management, best management practices with respect to water use and environmental impact through nitrogen leaching, climate change impact assessment, adaptation, and mitigation, carbon sequestration, plant breeding and genetics, as well as many others (Tsuji et al., 1998). DSSAT is now available as a free download from the DSSAT portal at www.DSSAT.net (Hoogenboom et al, 2023), with distribution to more than 25,000 users in more than 190 countries across the globe since 2019 (Hoogenboom et al., 2019). The source code of the Cropping System Model (CSM) of DSSAT is available from GitHub under the Open Source 3-Clause BSD license (https://github.com/DSSAT/dssat-csm-os). Experimental data for model calibration and evaluation of DSSAT also has played a critical role (Hoogenboom et al., 2012), resulting in the definition of the minimum data set and ICASA standards (White et al., 2013). The data that are distributed with DSSAT can be obtained from GitHub as well (https://github.com/DSSAT/dssat-csm-data). The DSSAT group also provides capacity building and training through an annual DSSAT International Training Workshop that is held at the University of Georgia (https://dssat.net/about/workshops/), as well as workshops across the globe based upon request by user groups.

Collaboration

As a crop modeling community, it will be important and critical to inform the scientific community as well as our stakeholders about the strength of the crop models, as well as the weaknesses, especially how crop models compare to AI models and predictions. Improved collaboration among modelers and modeling groups will also be needed as it is likely that some well-established models might disappear when senior scientists retire. The Agricultural Model Intercomparison and Improvement Project (AgMIP; www.AgMIP.org) has provided a community where crop modelers can meet, interact, and collaborate. The Agricultural Model Exchange Initiate (AMEI; https://crop2ml.org/#/AMEI/Vision) has provided an opportunity for the exchange of modules among crop modeling groups using the Crop Modeling Meta Language (Crop2ML) through support provided by INRAE (Midingoyi et al., 2021). Finally, iCROPM has provided a setting where crop modelers can meet and present their modeling results (Hoogenboom et al., 2020). Ultimately, these collaborations and initiatives should lead to better models to help address real-world problems under climate change for food security, optimum resource use, minimum environmental impact, and long-term economic and environmental sustainability.

References

Hoogenboom, G., J.W. Jones, P.C.S. Traore, and K.J. Boote. 2012. Experiments and data for model evaluation and application. In: p. 9-18. [J. Kihara, D. Fatondji, J.W. Jones, G. Hoogenboom, R. Tabo, and A. Bationo, editors] Improving Soil Fertility Recommendations in Africa using the Decision Support Systems for Agrotechnology Transfers (DSSAT). Springer, Dordrecht, the Netherlands.

Hoogenboom, G., C.H. Porter, K.J. Boote, V. Shelia, P.W. Wilkens, U. Singh, J.W. White, S. Asseng, J.I. Lizaso, L.P. Moreno, W. Pavan, R. Ogoshi, L.A. Hunt, G.Y. Tsuji, and J.W. Jones. 2019. The DSSAT crop modeling ecosystem. In: p.173-216 [K.J. Boote, editor] Advances in Crop Modeling for a Sustainable Agriculture. Burleigh Dodds Science Publishing, Cambridge, United Kingdom (https://dx.doi.org/10.19103/AS.2019.0061.10).

Hoogenboom, G. E. Justes, C. Pradal, M. Launay, S. Asseng, F. Ewert, and P. Martre. 2020. iCROPM 2020: Crop modeling for the future. The Journal of Agricultural Science (Cambridge) 158(10):791-793.

Hoogenboom, G., C.H. Porter, V. Shelia, K.J. Boote, U. Singh, W. Pavan, F.A.A. Oliveira, L.P. Moreno-Cadena, T.B. Ferreira, J.W. White, J.I. Lizaso, D.N.L. Pequeno, B.A. Kimball, P.D. Alderman, K.R. Thorp, S.V. Cuadra, M.S. Vianna, F.J. Villalobos, W.D. Batchelor, S. Asseng, M.R. Jones, A. Hopf, H.B. Dias, L.A. Hunt, and J.W. Jones. 2023. Decision Support System for Agrotechnology Transfer (DSSAT) Version 4.8.2 (www.DSSAT.net). DSSAT Foundation, Gainesville, Florida, USA.

International Benchmark Sites Network for Agrotechnology Transfer (IBSNAT). 1993. The IBSNAT Decade. Department of Agronomy and Soil Science, College of Tropical Agriculture and Human Resources, University of Hawaii, Honolulu, HI, p. 178.

Jones, J.W., G. Hoogenboom, C.H. Porter, K.J. Boote, W.D. Batchelor, L.A. Hunt, P.W. Wilkens, U. Singh, A.J. Gijsman, and J.T. Ritchie. 2003. The DSSAT cropping system model. European Journal of Agronomy 18:235-265 (https://doi.org/10.1016/S1161-0301(02)00107-7).

Midingoyi, C.A., C. Pradal, A. Enders, D. Fumagalli, H. Raynal, M. Donatelli, I.N. Athanasiadis, C. Porter, G. Hoogenboom, D. Holzworth, F. Garcia, P. Thorburn, and P. Martre. 2021. Crop2ML: An open-source multi-language modeling framework for the exchange and reuse of crop model components. Environmental Modeling & Software 142 (2021) 105055. (https://doi.org/10.1016/j.envsoft.2021.105055).

Tsuji, G. Y., G. Hoogenboom, and P. K. Thornton [Editors]. 1998. Understanding Options for Agricultural Production. Systems Approaches for Sustainable Agricultural Development. Kluwer Academic Publishers, Dordrecht, the Netherlands. ISBN 07923-4833-8. 400 pp.

White, J.W., L.A. Hunt, K.J. Boote, J.W. Jones, J. Koo, S. Kim, C.H. Porter, P.W. Wilkens, and G. Hoogenboom. 2013. Integrated description of agricultural field experiments and production: The ICASA Version 2.0 Data Standards. Computers and Electronics in Agriculture 96(1):1-12.

Session 2 - New formalisms, configuration and evaluations of STICS

SticsRpacks: R packages for STICS, where are we?

Samuel Buis[1], Patrice Lecharpentier[2], Rémi Vezy[3,4], Michel Giner[5], Cyrille Midingoyi[5]

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[4] Univ Montpellier, CIRAD, CNRS, INRAE, IRD, Montpellier, France ; [5] CIRAD, UPR AIDA, Montpellier, France

Keywords: R, model simulations, parameter estimation, model evaluation

Introduction

The SticsRPacks project has been initiated in the end of 2018 to develop tools for piloting the STICS model via the high-level R language. It is composed of a set of four R packages: SticsRFiles, SticsOnR, CroptimizR and CroPlotR. SticsRFiles and SticsOnR are dedicated to the STICS model. SticsRFiles aims at managing the STICS input and output files, and SticsOnR at managing and running STICS simulations. CroptimizR and CroPlotR are developed in a generic way to be coupled with any crop models. Their objective is to provide functions to easily implement, compare and automate parameter estimation and evaluation processes on crop models. All these packages are open-source, versioned and automatically tested using GitHub and have a Digital Object Identifier (DOI) assigned via ZENODO. They can be used with STICS starting from version 8.5.

Main features of SticsRFiles, SticsOnR, CroptimizR and CroPlotR

The purpose of SticsRFiles is to provide functions for manipulating STICS input and output files. These files are either JavaSTICS input files (XML format) or STICS input or output files (text format). The most basic functionalities are dedicated to reading and writing parameter names and values in these files. It also allows generating i) JavaSTICS input files from XLS spreadsheets and/or XML templates ; ii) STICS input files from JavaSTICS input files ; and iii) observation files from R `data.frames`.

The aim of SticsOnR is simply to run simulations with the STICS model from R. It provides different functions for that purpose. The most integrated one provides facilities for running simulations on a set of specified USMs using custom parameter values and returns simulated values to the user. It may handle crop rotations and distributed runs over machine CPUs.

CroptimizR offers a generic framework for linking crop models with up-to-date and ad-hoc parameter estimation algorithms implemented in external packages (both frequentist and Bayesian methods). It proposes a set of adapted goodness-of-fit criteria and an automatic parameter selection procedure following AgMIP Calibration Phase III protocol (Wallach et al., 2023). Initial values and constraints on estimated parameters can be provided (e.g. bounds and/or freely-defined constraints such as inequalities between parameters), as well as user-defined transformations for observed and/or simulated values of model output variables, in case they would not be directly comparable.

CroplotR aims at standardizing the process of analyzing crop models outputs using plots and statistics. The call to a simple plot function generates dynamic plots to analyze model simulation outputs at each time-step (possibly along with the corresponding observations), and scatter / residual plots to compare model simulation outputs with observations. A summary function computes standard goodness-of-fit statistics, that can be plotted in bar or radar charts. Different versions of models' outputs (e.g. from different models, model versions, or parameterizations) can easily be taken into account and compared, both in graphs and statistics. Plots returned by CroPlotR are ggplot objects and can thus be post-processed in R, for example to apply a theme, update the plot properties or extracting the plot data.

The generic packages CroptimizR and CroPlotR can be adapted to any crop model as long as users provide a wrapper for their model following a standard specification (see https://sticsrpacks.github.io/CroptimizR/articles/Designing_a_model_wrapper-.html).

The SticsRPacks package

The four packages described above are part of the SticsRPacks suite of packages. SticsRPacks is a wrapper package that eases the installation and loading of the four packages. It handles the compatibility between packages versions and provides an easy way to update them. It also includes an interactive tutorial covering the main functionalities of the SticsRFiles, SticsOnR, CroptimizR and CroPlotR packages. This tutorial can either be done locally, after installing the SticsRPacks package, or online, without any SticsRPacks installation.

Conclusion and perspectives

The SticsRPacks suite of packages starts to be widely used in the STICS community for applications such as multi-simulation (Operate project, ANR project REDELAC …) or calibration (Carsolel project, AgMIP Calibration project, EU Horizon IntercropVal-uES …). Training to the use of the packages is now integrated in the STICS training sessions.

The generic packages CroptimizR and CroPlotR have been integrated as standard tools in the corp models APSIM NextGen and SiriusQuality2. A collaboration with the DSSAT team is ongoing. These packages have been largely used in the context of the AgMIP calibration activity (https://agmip.org/crop-model-calibration-3/) to facilitate comparisons of parameter estimation methods on several crop models, e.g. with more than a dozen of different crop models to evaluate a calibration protocol for crop phenology (Wallach et al., 2023). Protocols and methods defined in this initiative are systematically implemented and documented in CroptimizR and CroPlotR in order to provide implementations of relevant methods for all crop model's users.

The next steps in the development of the SticsRPacks suite of packages include submitting the packages to the CRAN, and integrating or improving features, including the optimization of the generation of STICS model input files from JavaStics files, functions for analysing model inputs, definition of a standard protocol so that users can integrate their own goodness-of-fit criteria and/or optimization method in CroptimizR.

References

Wallach, D., Palosuo, T., Thorburn, P., Mielenz, H., Buis, S., Hochman, Z., Gourdain, E., Andrianasolo, F., Dumont, B., Ferrise, R., Gaiser, T., Garcia, C., Gayler, S., Hiremath, S., Horan, H., Hoogenboom, G., Jansson, P.-E., Jing, Q., Justes, E., … Seidel, S. J., 2023. Proposal and extensive test of a calibration protocol for crop phenology models. Agronomy for Sustainable Development (in press).

Development, deployment and execution of simulation workflows to study the impact of climate change on dairy farms

Patrick Chabrier[2], Graux Anne-Isabelle[1], Eric Casellas[2], Klervi Le-Floch[1], Patrice Le Charpentier[3], Renan Le-Roux[3], Fabien Ferchaud[4]

[1] PEGASE, INRAE, Institut Agro, 35590, Saint Gilles, France; [2] MIAT, INRAE, 31326, Castanet Tolosan, France; [3] AGROCLIM, INRAE, 84914, Avignon, France; [4] Eco&Sols, INRAE, 34060, Montpellier, France

Keywords : Virtual Research Environment, Crop Simulation Model, Simulation Workflow, High Performance Computing, OpenScience

Introduction

Like in the REDELAC [1] project whose objective is to assess the impact of the future climate and to anticipate the adaptive evolution of dairy farms in the Pays de Fougères, located in the Brittany region of France, virtual scientific experiments are involved and they rely on the collaborative development of workflows of simulations on appropriate computing resources.

The first stage of the REDELAC project is based on the use of the Stics simulator, because of its ability to represent a wide variety of rotational cropping systems. Moreover, the size of the overall simulation plan is estimated at around ten million simulations, making it very difficult to implement on an individual workstation.

In this working context, the first need is for a collaborative working environment between Stics and SticsRPacks development engineers, the scientists in charge of the REDELAC project and the engineers in charge of simulation workflow development and execution. The second priority is to benefit from solutions enabling the deployment and development of heterogeneous components in the form of processing workflows on high-performance HPC resources. And finally, in the context of a scientific project, mobilizing simulators and tools developed in a scientific context, we need to be able to quickly take into account inevitable evolutions in order to redeploy any part of the workflow, and if necessary to replay the various processes sparingly, as long as the project is not finished. This means that reuse during the project, but also reuse for communication and enhancement purposes, is an important issue.

To meet the requirements of the REDELAC project we are using a framework based on Github and Gitlab software forges, Docker and singularity Containers, CI/CD pipelines, the meso@LR HPC cluster and the SIWAA Galaxy Web workflow System. In this communication we explain how the design of this overall framework sustain the scientific project in many ways.

Materials & methods

The collaborative dimension of sharing Python[2] or R[3] code specific to the REDELAC project and more generic Stics or SticsRPack[4] code is fully covered by the forgeMIA[5] and GitHub[6] software forges. We can consider that the REDELAC system depends on 5 forge repositories. This enables us to have access to source code if necessary, and to control and track the development of the various components using the version management provided by Git[7]. Ultimately, this makes it possible to work with test or research versions of the main components. In addition, to facilitate the development of the workflow used to

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1 financed by INRAE's CLIMAE metaprogram over the period 2023-2024
2 https://www.python.org/
3 https://cran.r-project.org/
4 https://github.com/SticsRPacks/SticsRPacks
5 https://forgemia.inra.fr
6 https://github.com/
7 https://git-scm.com/

carry out the various treatments and simulations, we opted for the use of xlsx and csv tabular data files, Python and R scripts in particular, in order to make maximum use of the SticsRpacks library, whose aim is to facilitate the parameterization and analysis of Stics simulations.

When it comes to deploying tools on an HPC resource, we use Docker[8] and Singularity[9] containment mechanisms. In this way, we can abstract from the specificities of one operating system or another, use the storage registers of these containers[10] and run them on HPC-type resources. Another positive property is that these containers are defined in the form of recepies, a mechanism that contributes to traceability and reproducibility, by making explicit exactly which versions of the tools are used, as well as their dependencies. These recipes are themselves versioned.

The GALAXY[11]/SIWAA[12] framework, a website for editing simulation workflows, is permanently connected to the meso@LR[13] mesocenter in Montpellier. The Galaxy system features a native extension mechanism that makes it easy to add tools previously available on the Unix command line. Once these tools are available on SIWAA, they can be chained in WorkFlow. REDELAC has its own toolbox on SIWA, using R and Python scripts. SIWAA also provides data hosting services, which are hosted close to the computing cluster.

And finally, we use the CI/CD mechanisms of the forges to automate the generation of containers, the launch of tests for the tools developed, their deployment and installation on SIWAA(Fig:1). These procedures are available in the form of configuration files, also versioned within a forge project.

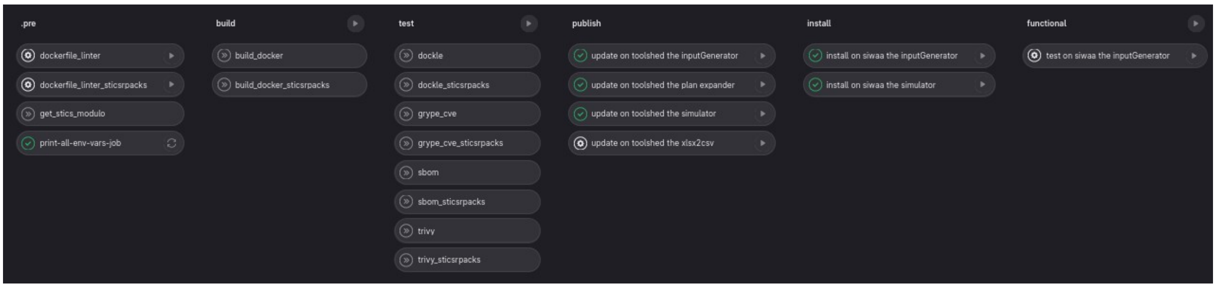

Figure 1: REDELAC CI/CD pipeline

Results and discussion

Based on an operational reference workflow, and the plan expansion specification, we have developed several components(Fig:2) for the SIWAA platform.

A simulation workflow is available for chaining tools, which can be configured by rotation type, climate scenario and spatial simulation plan. It allows all rotations planned for all climate scenarios to be launched in parallel, and remains durable and reusable.

Depending on the modifications made to the Stics simulator, or to the SticsRPacs packages thanks to containerization and the CI/CD chain, we are able to rapidly redeploy the tools, while preserving the previous versions. It is then possible to replay the impacted workflows in their entirety or in parts.

In terms of contribution, this agile working framework can be seen as encouraging the development of common tools, since modifications can be taken into account quickly and without risk, thanks to the persistence of the versions used.

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[8] https://www.docker.com/
[9] https://apptainer.org/
[10] https://opencontainers.org/
[11] https://galaxyproject.org/
[12] https://siwaa.toulouse.inrae.fr/
[13] https://meso-lr.umontpellier.fr/plateformes-hpc/

Another aspect is to consider simulation workflows accessible and shareable on a website, where data and processing are available on a permanent basis, without excluding access to code and data for local replay if necessary.

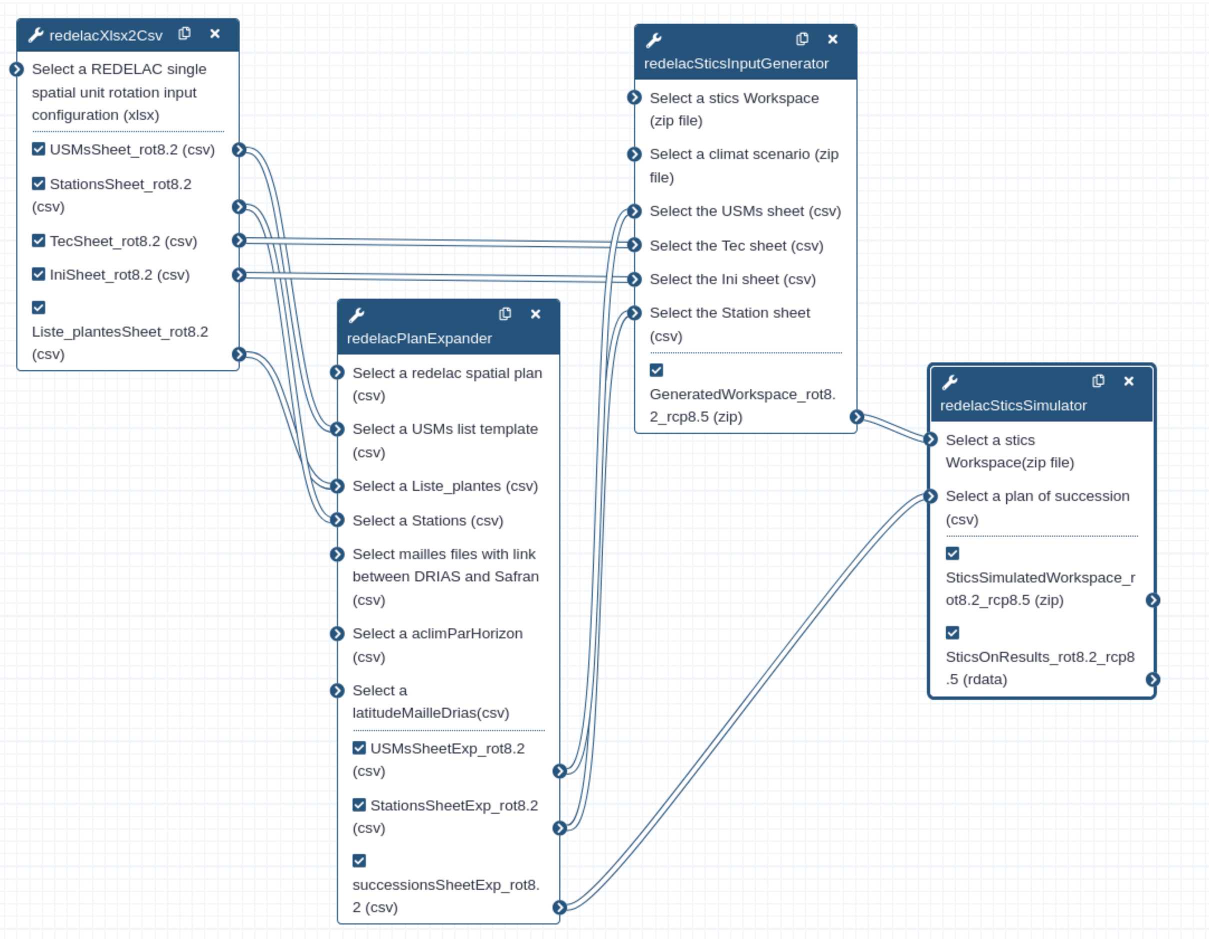

Figure 2: A Galaxy workflow using REDELAC components

Conclusions and outlook

The use of software forges, containers, CI/CD mechanisms, and a WEB workflow management framework linked to an HPC resource would appear to be an appropriate response to the needs of scientific projects such as REDELAC involving massive multi-simulation problems.

As part of REDELAC, we have decided to define specific tools and scripts as galaxy component, to take benefit of the good properties of such a framework in the domain of open and reproductible science. And even if we have already proposed some improvements, some of which have already been implemented, the REDELAC experience will enable us to take advantage of the needs, either by stabilizing the interfaces of the various components, or by reintroducing the scripts in the functionalities of the SticsRPacks packages.

To date, not all pre-processing and post-analyses have been integrated, as we have focused on simulations. It's also worth mentioning that we might want to integrate the workflow even further, by automating connections to upstream reference databases and downstream production of results data that could be published on dataverse like web sites.

And finally since the REDELAC project also aims to couple the Stics crop simulator with the AQAL-farm herd simulator, this will lead to further development of the REDELAC workflow and toolbox.

STICS ability to simulate long-term soil organic matter dynamics in crop-grassland rotations

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Keywords: soil organic carbon, grasslands, long-term datasets, France

Introduction

Grasslands ability to mitigate climate change by storing carbon (C) in soils is well recognised but difficult to quantify as it depends on many environmental and agronomical factors. Modelling the evolution of soil organic carbon (SOC) requires that models are sufficiently robust and accurate in their prediction. The ability of the STICS model to simulate SOC has already been evaluated in arable cropping systems, with satisfactory results (Autret et al., 2020; Yin et al., 2020; Clivot et al., 2020), but not yet in rotations that include temporary grassland, or in permanent grassland soils. This was the aim of this work, which was part of the French CarSolEl project.

Material and methods

We used a research version of the model derived from STICS v10.0, which fixes some bugs regarding senescence and return to the soil of the residual aboveground biomass after cutting. We revised grassland parameters based on previous works (Autret et al., 2020; Graux et al., 2020). We also activated options to simulate roots. We chosed "true density" to simulate both root emission and senescence versus time and depth, "continuous trophic link" to drive root length expansion by shoot growth, and "root deposition" to simulate a daily recycling of dead root biomass within the soil profile. We calibrated and evaluated STICS using data from three long-term French experimental trials, located in constrasted pedoclimatic conditions (Lusignan, Kerbernez and Theix sites), and offering data over 14 to 27 years for arable crops alone, arable crops alternating with temporary grassland and permanent grassland. We modified the value of six shoot parameters based on the literature to better represent the productive grassland functional groups present in the experimental trials. Then, data from the Lusignan trial were used to calibrate five root parameters involved in simulating the partitioning of assimilates between shoot and root, and the lifespan and N demand of the roots. We adjusted root parameter values on SOC stock in the top soil, mowing yield, N content of harvested grass, root C and nitrogen (N). The final grassland parameterization was then evaluated by simulating the Kerbernez and Theix trials, and comparing the simulations with the observed values. We evaluated the model's performance by calculating statistical criteria and comparing the root variables with the orders of magnitude known from the literature (Freschet et al. 2017; Legay et al. 2016; Mokany et al. 2006).

Results and discussion

With the final grassland parameterization, SOC dynamics at Lusignan are well simulated under both temporary and permanent grassland (Fig. 1A). In comparison with the STICS v10.0 model version and its standard calibration, the optimization slightly improves the quality of the simulation of grassland SOC and mowing yield, but significantly improves the simulation of the nitrogen content of the harvested grass. It also makes it possible to accurately simulate root C and N in grasslands, variables that were not previously simulated. Optimized values for the parameters involved in the dynamics of assimilate allocation between shoot and root parts reverse the curve compared with Autret et al. (2020), with preferential allocation to aerial parts at the start of grass regrowth and an allocation to the roots that increases as regrowth progresses. Evaluation of the new parameters at Kerbernez produced good results (Fig. 1B): the C loss observed under arable crop rotations is well simulated, as is the C storage observed under rotations with temporary grassland and under permanent grassland. At Theix (Fig. 1C), the evolution of SOC of the permanent grasslands is less well simulated, with a tendency towards destocking where observations indicate storage or slight destocking.

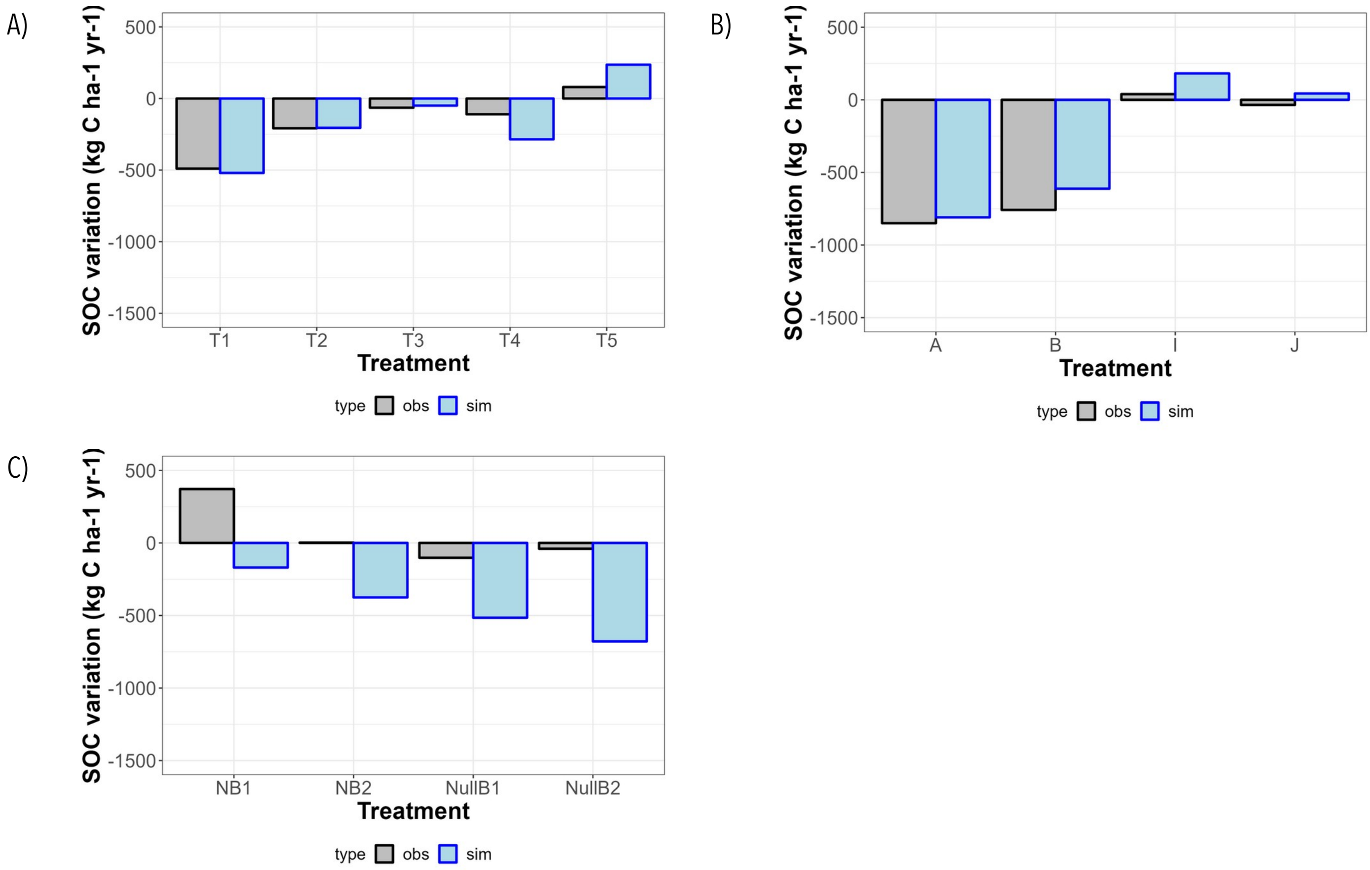

Figure 1. Simulated (blue bars) and observed (grey bars) SOC average annual variation at the three trials: A) Lusignan (SOC data over 15 years), B) Kerbernez (SOC data over 27 years) and C) Theix (SOC data over 7 years) for arable crops alone (treatments T1, A, B), arable crops alternating with temporary grassland (treatments T2, T3, T4, J) and permanent grassland sown (treatments T5, I) or already established (NB1, NB2, NullB1, NullB2) at the trial start.

However, SOC observations for this site were not available for the entire duration of the trial, but only at the beginning, and with a high degree of variability (standard deviation from 4 to 12 t C ha^{-1}), even at the start of the simulation. In general, the order of magnitude of the grass biomass, root/shoot ratio, root N content and root C/N ratio is in line with the expected values according to literature.

Conclusions and perspectives

Evaluation of the STICS model shows that it is able to reproduce observed trends in SOC evolution in rotations including temporary grassland and in permanent grassland soils. This exercise underlines the importance of long-term experimental trials and availability of root measurements (only present for one site in this study) to evaluate models and understand why, when it is the case, observed trends are not well reproduced. A differentiated initialization of root age at the start of the simulation, as well as taking into account a greater investment in roots by the plants in case of nitrogen deficiency, should make it possible to improve the SOC simulation for permanent grasslands already installed at the start of the simulation and grasslands under low N input management, respectively.

References

Autret B., Mary B., et al., 2020. Long-term modelling of crop yield, nitrogen losses and GHG balance in organic cropping systems. Science of the Total Environment, 710, 134597. https://doi.org/10.1016/j.scitotenv.2019.134597

Clivot, H., Ferchaud, F., et al., 2020. Simulating soil organic carbon dynamics in long-term bare fallow and arable experiments with STICS model, in: Book of Abstracts. Montpellier (France), pp. 70–71.

Freschet, G.T., Valverde-Barrantes, O.J., et al., 2017. Climate, soil and plant functional types as drivers of global fine-root trait variation. J Ecol 105, 1182–1196. https://doi.org/10.1111/1365-2745.12769

Graux, A.-I., Resmond, et al., 2020. High-resolution assessment of French grassland dry matter and nitrogen yields. European Journal of Agronomy 112, 125952. https://doi.org/10.1016/j.eja.2019.125952

Legay, N., Lavorel, S., et al., 2016. Influence of plant traits, soil microbial properties, and abiotic parameters on nitrogen turnover of grassland ecosystems. Ecosphere 7, e01448. https://doi.org/10.1002/ecs2.1448

Mokany, K.l, Raison R. J., Prokushkin, A. S., 2006. Critical Analysis of Root : Shoot Ratios in Terrestrial Biomes. Global Change Biol 12, no 1: 84-96. https://doi.org/10.1111/j.1365-2486.2005.001043.x.

Yin, X., Beaudoin N., et al., 2020. Long-Term Modelling of Soil N Mineralization and N Fate Using STICS in a 34-Year Crop Rotation Experiment. Geoderma 357: 113956. https://doi.org/10.1016/j.geoderma.2019.113956.

Modelling albedo and the energy budget using the STICS soil-crop model – Application to two Sub-Saharan sites

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Keywords: Biophysical effect, Energy partionning, Albedo, land management, conservation agriculture, modelling, STICS, energy budget

Introduction

Climate impacts of agricultural management practices such as mulching and no-tillage are usually evaluated with regard to soil organic carbon stock changes or greenhouse emissions. However, albedo effects of these practices that have been found to be of similar importance for climate change mitigation are usually ignored in this kind of assessment. This is even true for agricultural systems in Africa, which are less studied than temperate systems. In this study, we aim to assess the effect of land management on albedo dynamics and Radiative Forcing (i.e. climatic impact) in two long-term experiments established in Zimbabwe in 2013 with contrasting soil types. The Radiative Forcing (RF), is a metric used to quantify the change in Earth energy budget (radiation absorbed and emitted by the Earth) relative to an assumed default state (Betts 2000; Forster et al. 2007). The albedo of a cropland depends on soil properties, surface rugosity, soil moisture and coverage by plant litter, but also on plant density, phenology, architecture and spectral properties. Note that the latter may change for instance with phenology. The RFs resulting from land management changes are determined by their effects on the surface albedo dynamics but also by the solar radiation and atmospheric transmittance dynamics. Using a soil-crop model such as STICS coupled with a spatialization method that allows to represent changes in vegetation and soil properties is a promising solution to upscale RF related to albedo effects associated to land management changes at regional to global scales.

1. Modelling albedo using STICS

Surface albedo is the fraction of solar radiation reflected by Earth surface back to the space. Currently, STICS estimates surface albedo as a function of soil and vegetation albedo (Brisson et al., 2008). Soil albedo is a function of soil colour and moisture and also depends on the presence of mulch at the surface. Current formalism considers total leaf area index (LAI) , i.e. green and yellow parts taken together while field measurements suggest that albedo decreases with senescence leaves (Diop 2023). In this study, yellow LAI is introduced into the vegetation albedo equation in order to simulate the decrease during senescence.

2. Assessment of the energy budget components using STICS

Net radiation (RN) is simulated by STICS considering surface albedo and longwave radiations. Latent heat fluxes (LE) are estimated through the simulation of evapotranspiration but the current formalism of STICS to simulate soil evaporation is not relevant for sub-Saharan Africa. Therefore, this study will also try to improve the soil evaporation module based on field measurements in order to improve the estimates of albedo (that varies with soil superficial humidity) and the other components of the energy budget (i.e. ground heat flux sensible heat flux).

References

Betts, Richard A. 2000. « Offset of the Potential Carbon Sink from Boreal Forestation by Decreases in Surface Albedo ». *Nature* 408 (6809): 187‑90. https://doi.org/10.1038/35041545.

Brisson, Nadine, Marie Launay, Bruno Mary, et Nicolas Beaudoin. 2008. « Conceptual Basis, Formalisations and Parameterization of the STICS Crop Model », 301.

Diop, Souleymane. 2023. « Four-Component Net Radiometers to Quantify Albedo and Heat Fluxes in Conservation Agriculture ». *Nature Reviews Earth & Environment*, avril. https://doi.org/10.1038/s43017-023-00432-x.

Forster, Piers, Venkatachalam Ramaswamy, Paulo Artaxo, Terje Berntsen, Richard Betts, David W Fahey, James Haywood, et al. 2007. « Changes in Atmospheric Constituents and in Radiative Forcing », 106.

Using STICS under agrivoltaic shading conditions: How to consider the impact of panels on canopy and organs temperature?

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This abstract is a preview of a future PhD topic to be presented by the future PhD student - Joseph Vernier.

Keywords: Shading, agrivoltaism, canopy temperature, phenology, Computation Fluid Dynamic

1. Introduction

Agrivoltaism is the combination of photovoltaic electricity and agricultural production. Currently, our understanding of the impact of photovoltaic systems on the growth of crops is limited. Improving our knowledge of the physical phenomena that are modified by the solar panels is needed. The presence of panels modifies the crop microclimate at radiative, thermal and aeraulic scales. The phenomena are not homogeneous anymore and depend on the location on the field. To conduct agronomic simulations under such conditions, it is crucial to simulate both the changes of the microclimate and its effects on plants. This work shows the current limitations of using STICS [1] to simulate the phenological delays observed under shading conditions. Simulation data are compared with experimental data that are based on an experiment with an agrivoltaic system [2] for a wheat crop. This comparison enables us to identify ways of improving STICS, for instance by considering an alternative method to compute the thermal radiations under these specific conditions. It will lead to an upgrade of the formalisms in STICS, such as the computation of the radiative energy, to better consider the impact of these systems on the agricultural production.

2. Delayed phenology measured on a wheat crop

An experiment on winter wheat was conducted during the 2022-2023 season under an agrivoltaic system located in Seine-et-Marne (France). The objective was to assess the impact of shading on crop phenology. Weekly measurements of phenological stages (according to the BBCH scale) were taken for different shading conditions either under the agrivoltaic system or in the control zone without panels. Shading levels were measured using PAR sensors for the various conditions. Air temperature and wind speed sensors are also present for each modality. The physical properties of the soil were also characterized.

These measurements (Fig.1) show a delay in wheat growth under the agrivoltaic structures, from early bolting (BBCH 30) to physiological maturity (BBCH 89). For this last stage, a delay of 8 days is observed between the unshaded control and the agrivoltaic condition. With the STICS model calibrated on the meteorological data present in the field and a calculation of the ETP parameterized by the Penman method, the model simulates a delay of 2 days. This gap between the simulation and the field observation could be due to an incorrect calculation of phenological stage activations, which is also observed in agroforestry studies [3]. As the calculation of phenological stages is based on thermal calculations, which correspond to the integration of air temperature per days, it is important to analyze the impact of panels on air and canopy temperature.

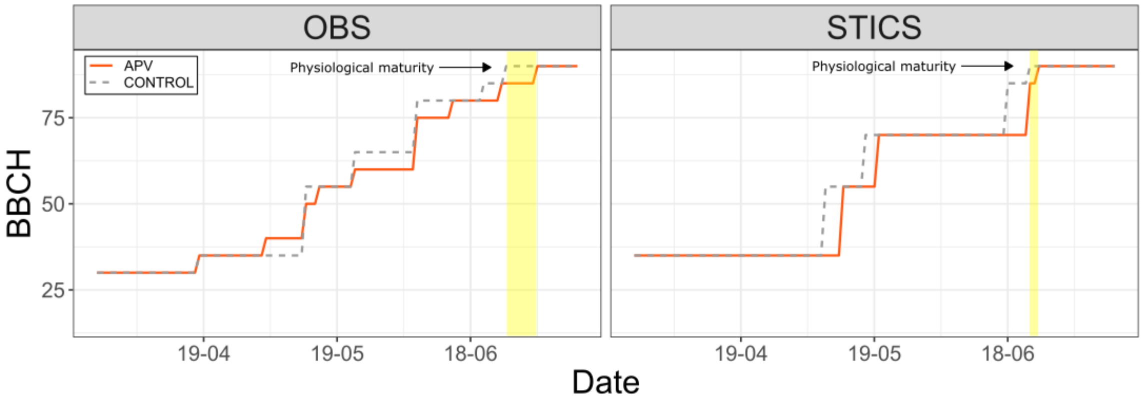

Figure 1 : Figure showing the evolution of phenological stages (BBCH) in a wheat crop over time. OBS corresponding to BBCH stages measured during experimentation. STICS representing the BBCH stages simulated by the crop model. Yellow represents the delay to reach physiological maturity between the control and Agri-PV conditions.

3. Link between air temperature and surface temperature

The graphs below (Fig.2) show the temperature under agrivoltaic panels against the temperature of the control zone without the agrivoltaic panels. The left one (air obs) and the center one (soil obs - due to the lack of crop temperature measurements) are based on experimental data while the right one (CROP stics) is based on simulation data. For the air temperatures, the difference between the measurements taken under the agrivoltaic system and the control is less than 1%. However, for the soil temperatures a reduction of 12% of the temperature under agrivoltaic panels for the same control temperature is observed. Then, for the canopy temperatures estimated by the STICS model, there is only a difference of 3% between the temperature under agrivoltaic panels and in the control zone. This is quite small compared with the difference of the soil temperature. Knowing that the soil temperature and the crop temperature are linked, it is possible that the STICS model incorrectly estimates the temperature of the canopy and the organs under agrivoltaic panels. That could explain the phenological delay not accounted by the model. To validate this hypothesis, further investigations are required, including thermal measurements of the canopy.

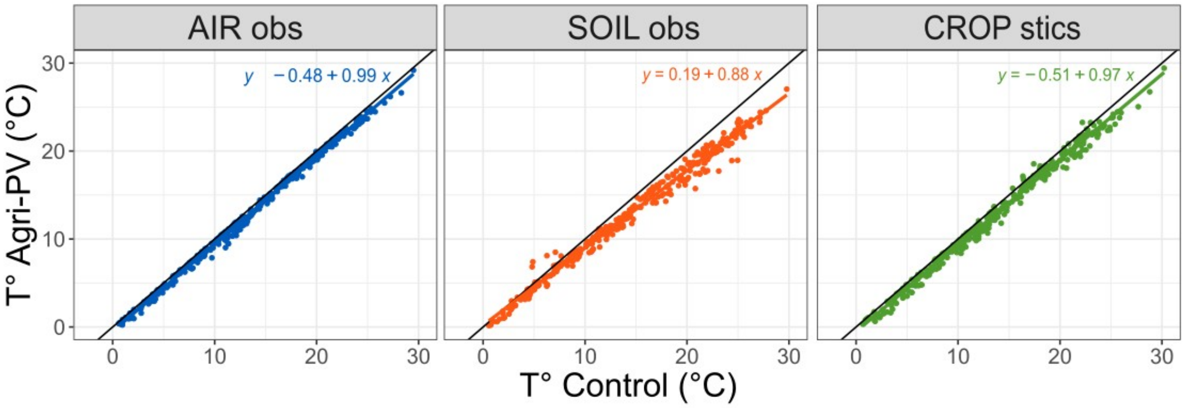

Figure 2: Figure showing the correlation between the daily temperature of 2023 measured on a control area without panels and below photovoltaic panels on the Agri-PV system, for air temperature AIR obs and soil surface temperature SOIL obs. CROP stics representing canopy temperature simulated by the crop model.

4. Modelling and tools to simulate microclimate

The presence of the panels modifies the microclimate and in particular the thermal energy balance at crop level. Canopy and organ temperatures are assumed to decrease under the panels. In the calculation of the net radiation of STICS no component allows to consider the presence of the sky partially obstructed by the solar panels and a potential modification of the longwave radiation. That will modify several ecophysiological processes, which may in some cases have negative impacts on the farmer's management of the crop (excess moisture in the grain, heterogeneity at harvest, etc.). There is therefore a need to adapt current crop models to first be able to take account of these microclimatic changes and then better design agrivoltaic systems.

The PhD work consists first in an in-depth study of the microclimate under the panels with additional instrumentation to measure microclimate (longwave radiation, wind speed fields and evapotranspiration) and measurements of canopy and organ temperatures. Secondly, the CFD code_saturne software will be used [4] to simulate the observed conditions. This software integrates a 3D radiative model to recalculate the radiation under the panels (long and short waves), with a ground model and a precise determination of the velocity field to consider the impact of the panels on the STICS inputs such as radiative energy, wind speed and ETP. Then, the doctoral student will continue his study by focusing on ways to couple this CFD software with STICS crop models, with the aim of better integrating the impact of the panels on the local climate at the canopy level.

5. References

[1] Brisson, N., Gary, C., Justes, E., Roche, R., Mary, B., Ripoche, D., Zimmer, D., Sierra, J., Bertuzzi, P., Burger, P., Bussière, F., Cabidoche, Y., Cellier, P., Debaeke, P., Gaudillère, J., Herault, C., Maraux, F., Seguin, B., & Sinoquet, H. (2003). An overview of the crop model STICS. European Journal of Agronomy, 95(3), 309–332. https://doi.org/10.1016/j.geoderma.2006.05.008

[2] Edouard, S., Combes, D., Van Iseghem, M., Ng Wing Tin, M., & Escobar-Gutiérrez, A. J. (2022). Increasing land productivity with agriphotovoltaics: Application to an alfalfa field. *Applied Energy*. https://doi.org/10.1016/j.apenergy.2022.120207

[3] Artru, S., Dumont, B., Ruget, F., Launay, M., Ripoche, D., Lassois, L., & Garré, S. (2018). How does STICS crop model simulate crop growth and productivity under shade conditions? *Field Crops Research*, (2017), 83–93. https://doi.org/10.1016/j.fcr.2017.10.005

[4] Archambeau F, Méchitoua N, Sakiz M. Code Saturne: A Finite Volume Code for the computation of turbulent incompressible flows - Industrial Applications. *International Journal on Finite Volumes*, 2004, 1 (1), http://www.latp.univ-mrs.fr/IJFV/spip.php?article3. ⟨hal-01115371⟩

Improvement of grapevine yield simulation in Champagne with the STICS model

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Keywords : Grapevine, Yield, STICS, Champagne, bunch number

Introduction

With climate change, we observe more variation of grapevine yield in Champagne due to an increased number of years with water stress, spring frost or both. Both phenomena can negatively impact grapevine yield during the growing season, one by reducing photosynthesis and the second by reducing the number of bunches. Moreover, water stress can also negatively impact yield for subsequent years due to a lack of reserves which can lead to a reduction of bunch number. The objective of this work was to improve *Vitis vinifera* L. yield simulation by the STICS model by using new capacities of the 10th version of the model and development of new formalisms to be able to launch chained simulations on the long term.

Material and Methods

We used data from an experiment called "Réseau Vigueur" conducted by the CIVC between 2018 and 2021 in Champagne. Different experiments varying in term of weed control, fertilization, grapevine variety and pruning are described in Table 1. The grapevine variety and pruning combinations used in this study are representatives of the most common combinations found in Champagne.

Model calibration and evaluation was done on chained simulations with an automatic simulation of grapevine topping. Data used for model evaluation were not used for model calibration. In the different sites, we have observed data concerning plant stages (bud burst, flowering, veraison, harvest date and senescence), plant growth (leaves, stems and fruits biomass and N content, leaf area index, bunch number) and soil (humidity and nitrogen content (mostly in the first 30 cm)).

Sites	Years	"Variety x pruning"	Treatments	Calibration	Distance from the meteorological station (km)
Belval	2018 to 2021	PM x Vm	Tem, Am, Min, Org	Min 2018 and 2019	≥ 3.8
Festigny	2018 to 2019	PM x Vm	Desh, Wsol	2018 and 2019	≥ 4.4
Les Riceys	2018 to 2021	PN x Gu	Tem, Am, Min, Org	Min 2018 and 2019	± 2
Plumecoq	2020 to 2021	PN x Ch	Am or Org		± 2
Urville	2018 to 2021	PN x Gu	Desh, Wsol	2018 and 2019	≥ 5.4
Vaudemange	2018 to 2021	CH x Ch	Desh, Wsol	2018 and 2019	≥ 5.8
Villers-Marmery	2018 to 2021	CH x Ch	Tem, Am, Min, Org	Min 2018 and 2019	± 2

Table 1: Description of experiments used for model calibration and evaluation. PM = Pinot meunier; PN = Pinot noir; CH = Chardonnay; Vm = pruning Vallée de la Marne; GU = pruning guyot; CH = pruning Chablis; Tem = No fertilization; Am = amendment; Min = mineral fertilization; Org = organic fertilization; Desh = chemical weed control; Wsol = mechanic weed control.

Results

Results presented in figure 1 are issued from simulations with common parameters but with or without activation of new options and formalisms. For simulations presented in figure 1.a and 1.b the bunch number was imposed with observed values.

The initial version of the model was unable to simulate observed yield variations due to the variation of bunch number (Figure 1a). Thanks to the development of a new formalism, the model was able to reproduce this variation with a good index of prediction quality (Figure 1b). We simply simulate a variable sink strength of fruits for C and N in function of bunch number relatively to maximal bunch number parametrized. However, the yield was underestimated during the year 2020 in some sites. First analysis allows us suspecting a lack of precision in climatic inputs data (high distance between plot and weather station).

To simulate the evolution of yield on the long term, we had to simulate the evolution of bunch number between years. Indeed, this plant parameter influences greatly the yield of grapevine (Figure 1b). Thus, we developed a new formalism to simulate bunch number in function of perennial reserves available at the beginning of the year and of nitrogen nutrition index of the crop during crop growth before flowering. The model was able to simulate the evolution of bunch number between years for various grapevine variety and pruning management with a good index of prediction quality (Figure 1c). However, simulation of bunch number slightly deteriorates yield simulation (Figure 1d) with an overestimation of some yields which is associated to an overestimation of bunch number.

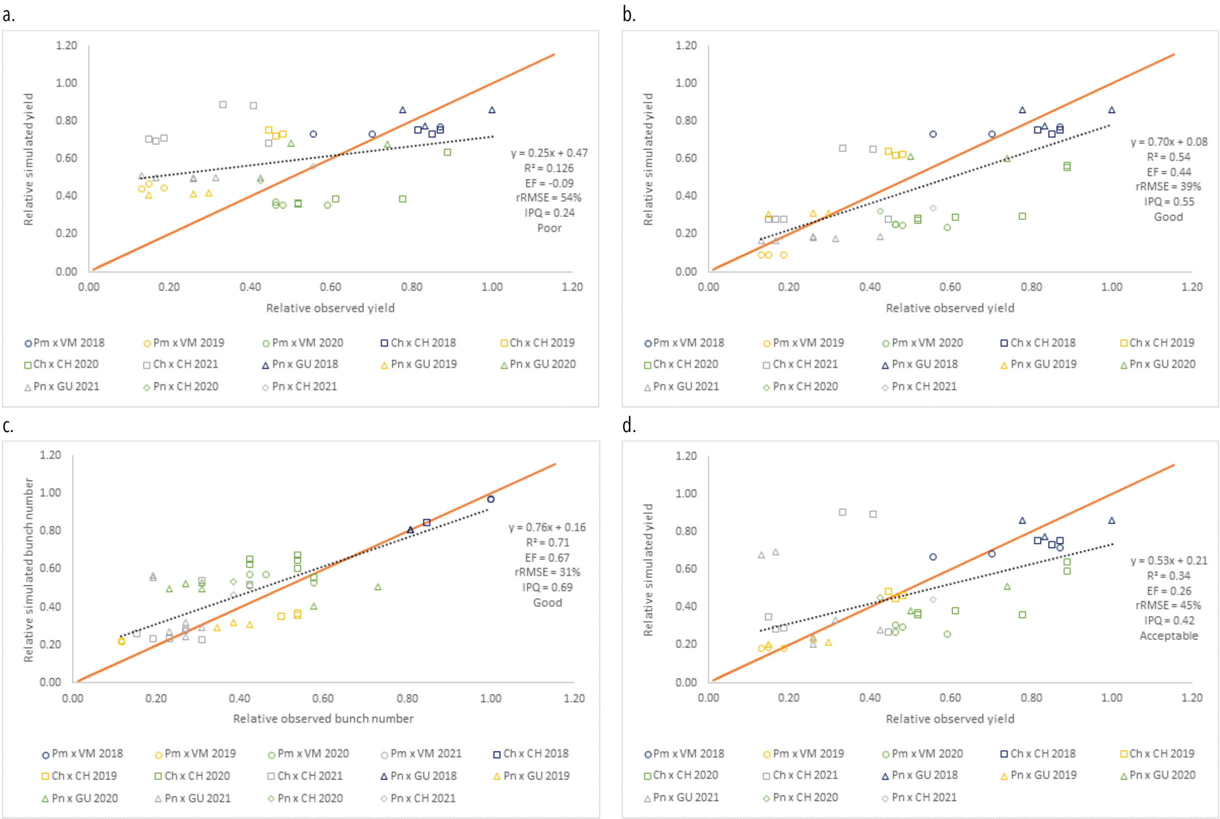

Figure 1: Grapevine yield simulated by the model on the evaluation dataset for different years, grapevine variety and pruning practices*. a: simulations with an imposed bunch number and no model modifications; b: simulations with an imposed bunch number and variable fruits sink strength; c and d: simulations with a simulated grape number and variable fruits sink strength. ** Data are presented in a relative way in function of the maximal observed value.*

Conclusions

Further evaluations of the model will be done thanks to new experiments. The STICS model will be used in a decision-making tool at the scale of the AOC Champagne to help winegrowers in the choice of their cultural practices. This work has been done as a part of the VitiCycle project funded by the "Comité Interprofessionnel des Vins de Champagne" and the "Region Grand-Est".

ISOP V10. Mise à jour du dispositif d'Information et de Suivi Objectif des Prairies (ISOP ; INRAE - Météo-France - MASA).

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Mots clefs: Prairie, climat, sols, région, production fourragère, modélisation, STICS.

Introduction

En vue de rationaliser la compensation financière aux éleveurs frappés par des calamités agricoles comme une sécheresse anormale par exemple, le système d'Informations et Suivi Objectif des Prairies (ISOP) mis en place par le Ministère de l'Agriculture et de la Souveraineté Alimentaire lui fournit des estimations de rendement des prairies temporaires et permanentes productives à l'échelle de la région fourragère (RF) à partir du modèle STICS (Ruget *et al.*, 2006, Triquenot *et al.*, 2020). Depuis 2000, il est opérationnel sur la France métropolitaine, y compris le pourtour méditerranéen mais hors petite couronne parisienne et Corse. La France métropolitaine est divisée en 209 RF définies comme des régions relativement homogènes du point de vue de leur sol, de leur climat et de leurs pratiques les plus caractéristiques (Hentgen, 1982). Les sols d'une RF sont caractérisés à partir de la carte pédologique de la France au Millionième. Les données météorologiques viennent du réseau de Météo-France, qui assure également la production opérationnelle des simulations au cours de l'année.

Dans chaque RF, les données météorologiques sont issues de données spatialisées à la maille de 0.125° de Météo France, soit approximativement 14 km. Ces données sont moyennées pour l'ensemble des mailles composant la RF, puis utilisées pour estimer avec le modèle STICS les productions de fourrage récoltable sur une sélection de 5 sols et de 5 pratiques par RF parmi les 150 et 30, respectivement, recensées sur le territoire métropolitain. L'indice ISOP de la RF est le rapport entre la production de biomasse cumulée récoltable et la moyenne de cette production sur la période 1989 – 2018. La moyenne des rendements et indices ISOP de la RF est pondérée en fonction de la répartition des sols et pratiques dans la RF. La simulation de la production est quotidienne, du 1er février au 31 janvier. Toutefois seule la production de mars à novembre est publiée, faute d'une bonne fiabilité sur les productivités hivernales généralement très faibles.

Parmi les milliers de situations caractérisées sur le terrain depuis 2000, de rares écarts entre observations et simulations ont été signalés et ont fait l'objet d'une analyse approfondie, avec vérification de la sensibilité du modèle aux causes possibles. Certaines observations de début de printemps et fin d'été notamment, ont mis en évidence notamment la nécessité d'une montée en version de STICS et la modification de certains paramètres.

Nous présentons la version de ce système mise à jour en 2021, qui maintenant utilise donc la version 10 de STICS (Beaudoin *et al.* 2023) et dont les données météorologiques ainsi que la distribution des surfaces en prairies sur le territoire ont été mises à jour parallèlement.

Les modifications d'ISOP

Les fonctions de la V10 par rapport à la version précédente.

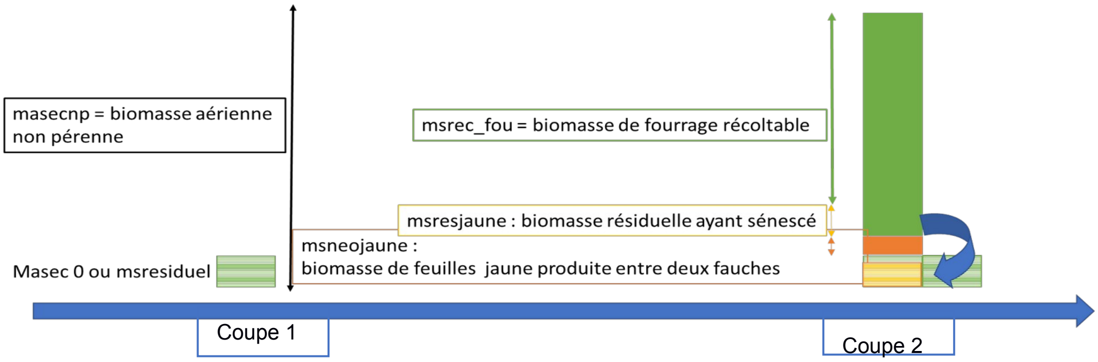

Figure 1. *Les noms des variables associées à la simulation des prairies dans STICS V10, et leurs états juste après la coupe et au jour de la coupe suivante.*

La version de STICS initialement utilisée dans ISOP était la V3. L'évolution sensible du code et d'un certain nombre de variables a contraint à une revue complète du système. Un travail informatique important a été effectué pour intégrer la nouvelle version de STICS V10 dans le système de production opéré par Météo-France. Les principales fonctions du modèle sont décrites dans Ruget *et al.* (2006) et Beaudoin et al. (2023). Les variables de sortie quotidiennes moyennées sur la RF et conservées à l'issue des simulations sont les biomasses aériennes totale et récoltable (figure 1), l'indice foliaire, l'indice de nutrition azotée, l'indice de stress hydrique, le niveau de la réserve utile. Les fichiers décrivant les caractéristiques des prairies en terme de sensibilité aux stress (réponse de la croissance à la sécheresse, à la température, au gel, à la nutrition azotée…) sont identiques pour les prairies temporaires et permanentes, dominées par les mêmes espèces. les prairies sont représentées par une graminée pérenne standard avec le fichier grass_plt.xml de STICS. La durée de vie des feuilles est affectée par la sénescence, définie par une durée de vie moyenne des feuilles. Cette durée est en outre réduite en cas de gel. La croissance des racines a été ajoutée à la version précédente pour moduler la réserve utile réelle avec un profil racinaire dans le sol montrant une décroissance de la densité racinaire avec la profondeur d'enracinement. La différence entre prairies temporaires et permanentes réside dans les pratiques, plus intensives en fertilisation et prélèvements (fauche ou pâture) pour les temporaires. La simulation de la luzerne dans la nouvelle version tient compte des derniers développements sur les pérennes.

Il n'existe pas de données observées de production fourragère proprement dites à l'échelle de la RF. Les écarts entre les simulations et les situations réelles ont donc été évalués qualitativement, sur la base d'interpellation des services régionaux ou bien d'analyse des sorties par l'équipe STICS elle-même. Pour la nouvelle version, des comparaisons avec des données départementales ont toutefois permis d'observer une évaluation correcte des niveaux absolus de production annuelle et surtout un bon comportement de l'indice ISOP.

La nature et la rareté des écarts avec les remontées de terrain depuis 2000, directement attribuables à des insuffisances de STICS ont amené à modifier le paramétrage avec parcimonie, et à jouer plutôt sur les valeurs de certains paramètres liés à la simulation de l'effet des stress sur la croissance et le développement de la prairie. Il s'agit en particulier de la réponse au stress hydrique initialement mal prise en compte par (i) un défaut de paramétrage de l'enracinement et de la réserve hydrique, (ii) un manque de sensibilité au déficit hydrique lui-même. L'introduction d'une simulation dynamique d'enracinement sensible aux conditions hydriques et aux coupes, ainsi que la modification des paramètres de stress ont permis de remédier partiellement à ces défauts. L'initialisation du modèle sur la profondeur de sol et la valeur de la biomasse récoltable minimum autorisant une fauche ont été revues.

Meilleure prise en compte de l'altitude dans les simulations

Les variables météorologiques varient fortement en fonction de l'altitude, en particulier la pluviométrie. Ces variations peuvent avoir un impact non négligeable sur l'indice ISOP.

Une mise à jour de la carte des prairies permanentes, artificielles (luzerne) et temporaires a été réalisée à partir des statistiques européennes de déclaration des surfaces par les exploitations agricoles, croisées avec la carte des RF. Ce travail, croisé ensuite avec le relevé topographique du territoire, a permis d'attribuer une altitude aux différents types de prairies composant les RF. Des séries météorologiques ont été constituées par tranche de 500 m pour chacune des RF, au lieu d'une série unique dans l'ancien système. Pour chaque combinaison pratique x sol, les simulations sont faites par tranche de 500 m au sein de chaque RF, avant calcul d'une moyenne pondérée à l'échelle de la RF entière suivant les altitudes des prairies.

Perspectives

A l'issue de ce travail de mise à jour achevé fin 2021, les parties prenantes ont mis en exergue quatre points en cours d'investigation. Premièrement, les simulations élémentaires à partir de la combinaison de pratiques et de sols dans chaque RF mettent en relief l'importance critique de la RU sur les indices ISOP. Ces simulations élémentaires permettraient d'arbitrer certains cas locaux en décalage avec la moyenne pondérée de la RF. Deuxièmement, une étude en cours va évaluer l'intérêt de réaliser les simulations avec des données climatiques à la résolution de 8x8 km, avant la pondération à la RF, pour améliorer la prise en compte de la variabilité spatiale des variables météorologiques. Troisièmement, si cela s'avérait important, il serait alors intéressant d'affiner l'attribution des sols aux points de grille météo. Enfin, quatrièmement, il serait tout à fait possible de prendre en compte l'évolution de la teneur en CO_2, avec son impact sur l'efficience de conversion du rayonnement visible en biomasse d'une part et sa modification de l'ETP d'autre part, tant pour la série de référence (380 à 415 ppm entre 1989-2018) que pour les simulations courantes.

References

Beaudoin, N., Lecharpentier, P., Ripoche-Wachter, D., Strullu, L., Mary, B., Léonard, J.,Launay, M., Justes, E. (2023). STICS soil-crop model: conceptual framework, equations and uses. QUAE ed.

Hentgen A. (1982) : "Une méthode pour améliorer la connaissance de la production disponible des surfaces herbagères au niveau national", Fourrages, 92, 15-49.

Ruget, F., Novak, S., Granger, S. (2006). Du modèle STICS au système ISOP pour estimer la production fourragère. Adaptation à la prairie, application spatialiséeF. Fourrages (2006) 186, 241-256

Triquenot, A., Ruget, F., Souverain, F. (2020). Le suivi de la pousse des prairies par le Ministère en charge de l'agriculture : aspects institutionnels et fonctionnels. Fourrages 244, 93-100.

AgMIP calibration: where are we and what are the results with the STICS model?

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Keywords : calibration, crop models, AgMIP

Introduction

Calibration is the process of estimating the parameters of simulation models. This is an important step in the processes of model development and application, as simulation results are largely determined by the model parameter values. However, it is often a long and difficult procedure, requiring expertise not only on the model and experimental data in hand, but also in scientific computing and statistics to be able to make multiple effective decisions all along the way. AgMIP's calibration activity began in 2016 with the aim of identifying calibration practices currently used by crop modellers and developing and testing guidelines to improve calibration practices. Several phases have been carried out to date. The first phase involved a survey of calibration practices. The second phase enabled 30 modeling groups to apply their usual calibration methods to wheat phenology datasets from France and Australia. The third phase developed a detailed protocol, tested by several modeling groups on the same datasets as for phase II. The fourth phase extends the approach to other types of observed variables. The STICS model has been involved in each phase of the project.

Practices of calibration in the crop modelling community – Phase I

In Phase I, a survey questionnaire was sent to the crop modelling community using different mailing lists and websites. It focused on specific aspects of the calibration activity and on its context of application. The results from 211 responses were reported in (Seidel et al, 2018). Eight responses referred to the STICS model. This survey showed that there is a very large variability in approaches to crop model calibration including for example the way the parameters to estimate are chosen, the method used to perform the estimation, or the way data representing multiple different outputs are taken into account. From this survey, it seemed clear that we are far from having a consensus on how to properly calibrate crop models.

Outcome of the unguided calibration step - Phase II

Phase II confirmed this assertion: among the 30 modeling groups that participated, quite different decisions were made for the calibration of their models, even within modeling groups using the same models. The different groups chose to estimate between 1 to 7 parameters for the French dataset and from 1 to 10 parameters for the Australian dataset. Most of the groups used a frequentist approach, and, among them, almost half used trial and error to estimate the parameters values. The team behind the STICS model chose to calibrate it using a Bayesian method (DREAM-zs). The parameters considered, selected by expertize, were the sum of photo-vernalo-thermic development unit corresponding to each observed phenological stages, the number of vernalising days (JVC), and, only for the Australian dataset, the maximum phasic delay allowed due to stresses (stressdev). In total, 3 parameters were estimated for the French dataset and 6 for the Australian dataset.

For the French dataset the average of the Mean Absolute Error (MAE) of the different observed stages ranged from 3.47 to 12.81 days depending on the modeling group (Wallach et al, 2021a). The MAE obtained for STICS was 4.81 (seventh lowest value out of 27 modelling groups). For the Australian dataset, it ranged from 6.3 to 20 days, with a median of 9 days (Wallach et al. 2021b). The MAE obtained for STICS was 6.6 (third lowest value over 28). On average, for both exercises, the MAE varied between 5.37 and 20 (Wallach et al, 2021c), and was 5.7 for STICS, which is the fourth best result out of 28. No model was ranked first on both datasets. The ensemble mean and median perform better than any individual model.

Toward proposition of protocols and tools for the calibration of crop models – Phase III and IV

The protocol proposed in phase III for calibrating phenology consisted in a specific forward regression algorithm based on the minimization of ordinary least squares using a multi-start Nelder Mead simplex method (Wallach et al, 2023). It performs an automatic selection of the estimated parameters among a set of candidates proposed by the user. Compared to the results obtained in phase II, the use of this protocol significantly reduced the error in predictions for the evaluation data and reduced the variability of the predictions between modeling groups by 22%. Concerning STICS, the results have been improved for the French dataset but degraded for the Australian dataset, compared to those obtained in phase II. The list of selected parameters was different: 2 and 3 parameters selected for the French dataset (depending on the cultivar) and 7 and 8 for the Australian dataset (depending on the information criteria used).

A protocol was then proposed in phase IV for calibrating multiple variables. It is composed of 2 steps. The first step successively applies the method used in phase III to the different types of observed variables. A weighted least square minimization combining the observations of all the variables is then applied in a second step to estimate the values of the parameters selected in the first step. The first results obtained while testing the STICS model with synthetic data confirmed the potential interest of this approach.

The method used in phase III was implemented in the CroptimizR package (Buis et al, 2023). It was used with more than a dozen crop models in this phase. An implementation of the method proposed in phase IV, based on this package, has been tested using synthetic data and will be available to all users for application on a real dataset.

References

Buis, S., Lecharpentier P., Vezy R., Giner, M., 2023. CroptimizR: A Package for Parameter Estimation, Uncertainty and Sensitivity Analysis for Crop Models https://github.com/SticsRPacks/CroptimizR. https://doi.org/10.5281/zenodo.4066451.

Seidel, S. J., Palosuo, T., Thorburn, P., & Wallach, D., 2018. Towards improved calibration of crop models–Where are we now and where should we go? European Journal of Agronomy, 94.

Wallach, D., et al., 2021a. How well do crop modeling groups predict wheat phenology, given calibration data from the target population?. European Journal of Agronomy, 124.

Wallach, D., et al., 2021b. Multi-model evaluation of phenology prediction for wheat in Australia. Agricultural and Forest Meteorology, 298.

Wallach, D., et al., 2021c. The chaos in calibrating crop models: Lessons learned from a multi-model calibration exercise. Environmental Modelling & Software, 145.

Wallach, D., et al, 2023. Proposal and extensive test of a calibration protocol for crop phenology models. Agronomy for Sustainable Development (in press).

Session 3 - Modeling of cropping systems and biogeochemical cycles to support the agroecological transition

Simulation of long-term water, nitrogen and carbon dynamics for contrasted arable cropping systems with the STICS model

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Keywords: model evaluation, yield, nitrogen, water, soil organic carbon

Introduction

Soil-crop models can be used as predictive tools to evaluate the agronomic and environmental performances of cropping systems. STICS has been shown to simulate the biomass and nitrogen (N) of crops as well as the water and nitrate content of the soil, with a good accuracy, at an annual scale over a wide range of agro-environmental conditions (Coucheney *et al.*, 2015). However, long-term evaluations including soil organic matter dynamics have been achieved only in a limited number of situations (*e.g.* Autret et al., 2020). This study aimed to assess the STICS model ability to simulate long-term water, N and carbon (C) dynamics for contrasted agricultural management practices.

Materials and methods

We used the arable site of the ACBB (agroecosystems, biogeochemical cycles and biodiversity) long-term experiment, located in Estrées-Mons, northern France. The experiment was set-up in 2009-2010. The soil is a deep silt loam (Haplic Luvisol) and the climate is temperate. The six main treatments include a large range of management practices: conventional (CONV), reduced-tillage (RT), reduced-tillage combined with residue removal (RT-RR), reduced nitrogen (RN), reduced nitrogen with leguminous crops (RN-LEG), residue removal and perennial crop (RR-PER). Two additional treatments are under organic management since 2016, with or without alfalfa in the rotation. All treatments follow the same six-year baseline arable crop rotation, including spring and winter cereals, rapeseed, spring pea and cover crops. RR-PER included six years of switchgrass (*Panicum virgatum*) followed by six years of arable crops. In RN-LEG, legumes were used as cover crops and alfalfa was cropped during the first two years of the second rotation. Available observed data were crop aboveground biomass and N content (one to three times per crop cycle), grain yield and N content, soil mineral N and water stocks (two to three times per year) and soil organic C and N (SOC and SON) stocks in 2009 and 2015.

We used STICS v10 (Beaudoin *et al.*, 2023) without site-specific calibration. However, plant files were modified to consider dynamic N accumulation in the roots and its turnover during crop growth (Autret et al., 2020). Simulations started in February 2009, one year before the beginning of the treatments, and ran continuously until 2021. STICS was evaluated against observed data using standard statistical criteria provided by the CroPlotR package (Vezy *et al.*, 2023).

Results and discussion

STICS was able to simulate crop aboveground biomass with a good overall performance (Table 1) for the different crop species and treatments (RMSE = 2.3 t DM ha^{-1}, rRMSE = 37%). However, the larger biomass values were slightly overestimated. The performance for simulating grain yield was also quite good (RMSE = 2.0 t DM ha^{-1}, rRMSE = 32%), although spring barley yields were underestimated. Overall, the crop N content was well predicted, but slightly less than biomass.

The simulated soil water dynamics were consistent with the measurements (Table 1). STICS performance was good for the soil water content in the 0-30 cm layer as well as for the total soil water stock in the 0-150 cm layer (rRMSE = 12 and 9%, respectively). Performance in simulating soil mineral N dynamics was less satisfactory. The total soil mineral N stock (0-150 cm) was on average underestimated by 20.5 kg N ha^{-1}. In the 0-30 cm layer, the range of variation of observed values was limited as they were obtained at harvest and at the end of winter, *i.e.* far from fertilization events, which led to large rRMSE and negative EF.

Regarding SOC and SON stocks in 2015, results were satisfactory for conventional annual cropping systems (CONV, RT, RT-RR) and also for RN-LEG (Table 1). However, the stocks were overestimated by STICS in the treatment with the lowest N availability (RN, +1.8 t C ha^{-1}) and underestimated after switchgrass cropping (RR-PER, -3.8 t C ha^{-1}).

Table 1: Number of observations (n), mean of observed values and main statistical criteria used for the evaluation of STICS against different measured variables (RMSE = root mean square error; rRMSE = relative RMSE; R^2 = coefficient of determination; EF = model efficiency).

Variable	n	Mean obs.	Bias	RMSE	rRMSE (%)	R^2	EF
Aboveground biomass (t DM ha^{-1})	303	6.2	1.0	2.3	37.2	0.88	0.83
Grain yield (t DM ha^{-1})	89	6.3	-0.3	2.0	31.6	0.53	0.51
Aboveground N (kg N ha^{-1})	194	105.6	10.3	49.5	46.9	0.48	0.33
Grain N (kg N ha^{-1})	76	111.5	-7.0	56.8	51.0	0.06	-0.74
Water content 0-30 cm (%)	182	21.2	0.6	2.5	11.7	0.80	0.73
Soil water stock 0-150 cm (mm)	182	446	16	40	9.1	0.81	0.76
N-NO_3 0-30 cm (kg N ha^{-1})	182	20.3	-6.3	17.6	86.8	0.03	-0.46
N-NH_4 0-30 cm (kg N ha^{-1})	182	5.7	1.2	4.3	74.6	0.03	-0.23
Mineral N 0-150 cm (kg N ha^{-1})	182	61.4	-20.5	37.5	61.1	0.17	-0.46
SOC stock 0-35 cm 2015 (t ha^{-1})	8	48.2	-0.9	2.1	3.0	0.24	0.01
SON stock 0-35 cm 2015 (t ha^{-1})	8	5.24	-0.04	0.14	1.9	0.22	-0.19

To conclude, this study shows that STICS is a useful assessment tool of long-term environmental performance in arable cropping systems and provides information on areas for improvement.

References

Autret, B., Mary, B., Strullu, L., Chlebowski, F., Mäder, P., Mayer, J., Olesen, J.E., Beaudoin, N., 2020. Long-term modelling of crop yield, nitrogen losses and GHG balance in organic cropping systems. Science of the Total Environment 710, 134597. https://doi.org/10.1016/j.scitotenv.2019.134597

Beaudoin, N., Lecharpentier, P., Ripoche, D., Strullu, L., Mary, B., Leonard, J., Launay, M., Justes, E., 2023. STICS soil-crop model. Conceptual framework, equations and uses, Versailles, Éditions Quæ. http://doi.org/10.35690/978-2-7592-3679-4

Coucheney, E., Buis, S., Launay, M., Constantin, J., Mary, B., García de Cortázar-Atauri, I., Ripoche, D., Beaudoin, N., Ruget, F., Andrianarisoa, K.S., Le Bas, C., Justes, E., Léonard, J., 2015. Accuracy, robustness and behavior of the STICS soil-crop model for plant, water and nitrogen outputs: evaluation over a wide range of agro-environmental conditions in France. Environmental Modelling & Software 64, 177-190. https://doi.org/10.1016/j.envsoft.2014.11.024

Vezy, R., Buis, S., Lecharpentier, P., Giner, M., 2023. CroPlotR: A Package to Analyze Crop Model Simulations Outputs with Plots and Statistics. https://github.com/SticsRPacks/CroPlotR, https://doi.org/10.5281/zenodo.4442330

Using a long term experiment with a wide range of management practices to challenge N_2O emissions modelling with the STICS model

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Keywords: N_2O emissions, agricultural practices, model evaluation, long-term differentiation

Introduction

Accurately predicting how agricultural practices influence N_2O emissions remains an issue to help designing efficient cropping systems. N_2O emissions are driven by numerous interacting processes and are strongly dependent on environmental conditions, which makes fluxes span over orders of magnitude, with strong temporal and spatial variability. In that context, long term continuous measurements of N_2O emissions combined to exploration of a wide range of agricultural practices provide strong test conditions for measuring the performances of models in predicting N_2O emissions from cropping systems, which we did here using the STICS model and the arable site of the ACBB long term experiment.

Materials and methods

The experiment used is located in Estrées-Mons (northern France) on a deep silt loam soil. Treatments include a large range of management practices: conventional, reduced-tillage, reduced-tillage combined with residue removal, reduced nitrogen, reduced nitrogen with leguminous crops, residue removal and perennial crop, and more recently organic farming with or without alfalfa in the rotation. N_2O fluxes are measured with automatic chambers since 2011 on the different treatments which allowed to obtain a quasi-continuous monitoring of N_2O emissions, combined with measurement of the main control variables. We used STICS v10 (Beaudoin *et al.*, 2023) without site-specific calibration, with simulations starting in February 2009, one year before the beginning of the treatments, and run continuously until 2021. STICS evaluation against data other than N_2O emissions was done in a complementary work (Ferchaud et al., 2023). We focused here on the analysis of model performances related to N_2O emissions prediction, how the influence of management options is reflected, and on how environmental variables and the resulting domination of nitrification and denitrification shape model performance.

Results and discussion

Model performance for simulating crop growth, soil temperature and soil water dynamics were good overall (Ferchaud et al., 2023). Prediction quality was lower for mineral nitrogen, especially after alfalfa destruction. With model default values for the nitrification and denitrification potential, cumulative N_2O emissions over the 10 years were overestimated by a factor 2 on the conventional management treatment, while both the final value and its build-up through time were very close to observations if only nitrification was considered. As complete absence of denitrification is unlikely, that suggest both an overestimation of nitrification and denitrification. Both potential rates were thus first adapted to better fit results from the conventional management treatment before looking at the dynamics of emissions and the effect of management practices, keeping the same adaptation as for conventional management treatment for other treatments.

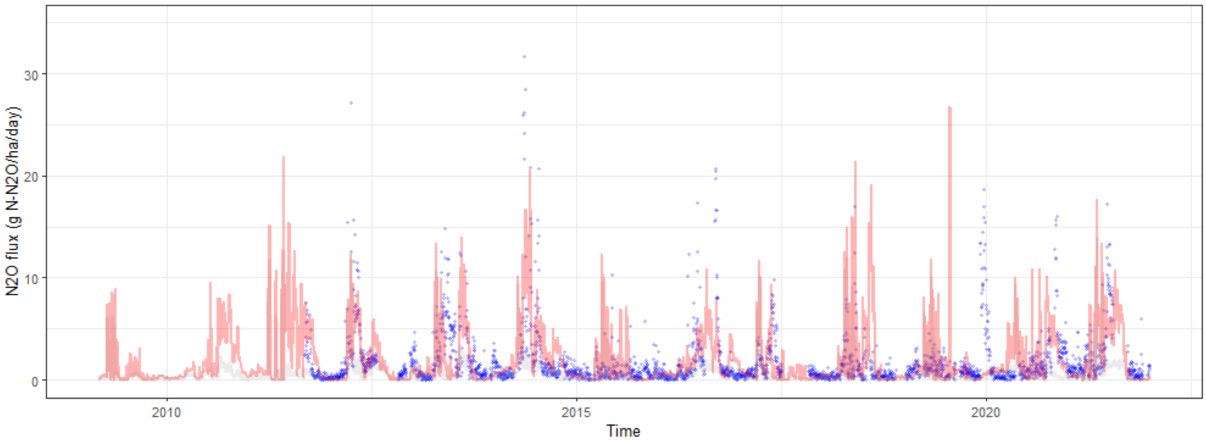

Figure 1: Observed and simulated N_2O emission for conventional management after calibration of potential values of nitrification and denitrification rates. Three observed values above 40 g N-N_2O/ha/jour are masked. Blue dots: observations, light red line: total N_2O emissions, light gray: N_2O emissions from nitrification.

Although the model was able to capture the main features of the temporal dynamics of emissions (Figure 1), it also failed at reflecting some of the events (missed peaks, under or over estimation of fluxes amplitude). Simulation of other treatments than the conventional management one indicated that, despite the same limitations for simulating temporal dynamics, the effect of reduction in mineral nitrogen input and progressive substitution by nitrogen originating from legumes was well captured, as well as the very limited effect of soil tillage or residue removal (Table 1). On the contrary, a strong underestimation was observed for organic farming with alfalfa.

Table 1: Comparison of observed (N_2O obs) and simulated (N_2O sim) cumulative N_2O emissions (kg N-N_2O/ha) for the different treatments of the ACBB long term experiment. Accumulation is done over the whole period but excluding days where measurements are not available (treatment comparisons can thus be misleading).

Treatment	Period	N_2O obs	N_2O sim
Conventional management	2012-2022	5.6	5.6*
Reduced-tillage	2012-2022	5.9	6.3
Reduced-tillage and residue removal	2012-2022	5.3	5.5
Reduced nitrogen	2012-2022	2.3	2.9
Reduced nitrogen with leguminous crops	2013-2022	3.1	3.0
Residue removal and perennial crop	2014-2022	3.6	3.6
Organic farming without alfalfa	2017-2022	1.9	2.0
Organic farming with alfalfa	2017-2022	3.1	1.0

Continuous evaluation of model performance at the daily scale also opens the way for analysing how the level of model performance depends on the dominant processes at play, on the environmental conditions, and ultimately better understand the strengths and limits of the model to improve it.

References

Beaudoin, N., Lecharpentier, P., Ripoche, D., Strullu, L., Mary, B., Leonard, J., Launay, M., Justes, E., 2023. STICS soil-crop model. Conceptual framework, equations and uses, Versailles, Éditions Quæ. http://doi.org/10.35690/978-2-7592-3679-4

Predicting the short- and long- term effects of recycling organic wastes in cropping systems with the PROLEG tool

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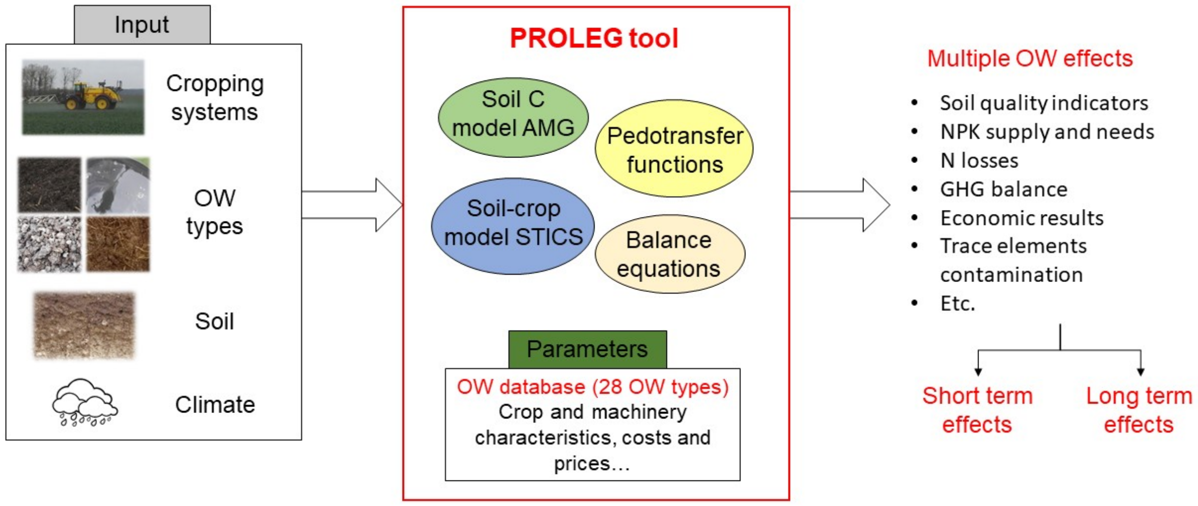
Keywords : C storage, GHG balance, multicriteria assessment, N losses, NPK supply, organic waste



Extract from a paper published in Soil Use Management (Levavasseur & Houot, 2023)

Recycling organic wastes (OWs) in agriculture may increase soil organic carbon (SOC), improve soil chemical, physical and biological properties and make mineral fertilizer savings possible. Some drawbacks are related, for example, to N losses, soil contamination or greenhouse gas (GHG) emissions, and may counterbalance the interest in OW recycling. Some of these effects are only noticeable after repeated applications over several years and depend on OW type, on their insertion in cropping systems (e.g., rate, period) and on pedoclimatic conditions. The optimization of OW recycling should promote their positive effects and limit their negative effects. Various simulation tools can predict some OW effects and help with this optimization. However, despite many existing tools, dedicated tools with a multicriteria approach of OW effects and the ability to consider various OWs, soils, climates and cropping systems are still missing. We developed the PROLEG tool to predict the short- and long-term multiple effects of OW application in agriculture at the field scale. The tool combined the soil-carbon model AMG to predict SOC changes, the soil-crop model STICS to predict N supply and N losses, some pedotransfer functions to predict the evolution of some soil properties related to SOC and simple balance equations to predict mineral fertilizer needs, GHG balance, soil contamination with trace metals and economic results. The tool also embedded many parameter tables, especially related to the characteristics of diverse OWs. The tool required easily accessible soil properties and a description of the cropping systems in a simple spreadsheet. It automatically computed mean and detailed output variables in tables and figures. We illustrated the use of the tool with a simple case study. The tool has already been used with farmers to design new cropping systems and to support public policy related to anaerobic digestion.

References

Levavasseur, F., & Houot, S., 2023. Predicting the short- and long-term effects of recycling organic wastes in cropping systems with the PROLEG tool. Soil Use and Management, 39(1), 535–556. https://doi.org/10.1111/sum.12856

Estimating CO_2 fluxes (GPP, RECO, NEE) of diversified crop rotations from STICS outputs

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Keywords : Net Ecosystem Exchange; Crop model; Gross Primary Productivity; Autotrophic respiration; Heterotrophic respiration; Carbon balance; STICS

Summary

CO_2 emissions constitute 75% of global net anthropogenic emissions (IPCC, 2013), inducing climate change. To study its impacts on cropping systems, modelling studies are primordial, enabling to investigate changing pedoclimatic conditions and to prospect potential farming systems with innovative management. However, it is primordial that crop models, when evaluating climate change impacts, consider the interactions between soil organic carbon and carbon dioxide (Basso et al., 2018) not only at the level of a single crop but for whole crop rotations.

With this goal in mind, we used the outputs of STICS in its standard pre-parameterized version (v9.2) to model the Gross Primary Productivity (GPP), the Ecosystem Respiration (RECO) and the Net Ecosystem Exchange (NEE). We based on the 16-year crop rotation of the ICOS BE-LON site (Belgium), which comprises five different crops (winter wheat, sugarbeet, maize, potato, cover crop), to calibrate and validate our methodology for computing CO_2 fluxes.

GPP is derived from the autotrophic respiration and from the Net Primary Productivity, which is calculated through the daily change in plant carbon (C) pools. The autotrophic respiration (AR) is computed from the plant biomass, the plant nitrogen concentration and GPP. The heterotrophic respiration (HR) was already an output of the STICS model, derived from the mineralization of residues and organic matter. Finally, RECO is the sum of AR and HR and NEE the sum of RECO and GPP.

The comparison of the simulations with the CO_2 fluxes measured on the BE-LON site indicated that the model is able to simulate accurately daily CO_2 fluxes (efficiency EF equal to 0.79 for GPP, 0.59 for RECO and 0.67 for NEE). Concerning the cumulated fluxes of the whole 16-year crop rotation, it appeared that the model evaluates this carbon budget accurately for RECO, with a slight underestimation (normalized deviation ND = 15.7%), and very accurately for GPP (ND = 5.12%). But for NEE, the relative overestimation induced by the model is higher (ND = 62.2%). This indicates that a more precise estimation of HR, whose computation is directly made by the STICS model, is required to obtain reliable net C budgets. This also suggests that the model, coupled with our external calculations, is for the moment more appropriate to establish comparisons between contrasted farming systems under various agro-pedoclimatic conditions rather than to provide absolute carbon budgets. We also discussed the influence of different environmental drivers on crop rotations CO_2 fluxes, and the model showed to be able to reproduce the trends observed with the field measurements.

Our generic methodology is easily transferable to any soil-crop model and proved to be a valuable tool to investigate the CO_2 exchanges of various crop rotations in historical and future climatic conditions.

References

Basso, B., Dumont, B., Maestrini, B., Shcherbak, I., Robertson, G. P., Porter, J. R., ... & Rosenzweig, C. (2018). Soil organic carbon and nitrogen feedbacks on crop yields under climate change. *Agricultural & Environmental Letters*, *3*(1), 180026. https://doi.org/10.2134/ael2018.05.0026

IPCC (2013). *Climate Change 2013: The Physical Science Basis.* Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp.

Conceptualization, formalisms and first evaluations of a phosphorus module for the STICS soil-crop model

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Keywords: nutrient, soil-plant P model, P response, simulation

Introduction

Crop phosphorus (P) nutrition is one of the key sustainability challenges of the 21st Century (Cordell and White, 2014). Crop models are pertinent tools to study and manage phosphorus in agro-ecosystems. However, the modeling of P is suffering a delay as compared to nitrogen and carbon. A major reason of this delay is the difficulty in formalizing a semi-mechanistic model that predicts adequately the temporal and spatial evolution of soil P availability (Das et al., 2019).

Formalization

We propose a phosphorus sub-model to the STICS soil-crop model based on the FUSSIM-P model (Mollier et al., 2008). It aims to simulate daily crop demand, soil P availability, potential and actual uptake of P by the crop, partitioning of P within plant compartments, as well as the feedback of P deficiency on plant growth and development. The formalisms are based on agronomic and biogeochemical concepts such as dilution curves, nutrition and harvest indexes, diffusion and mass-flow fluxes and sorption curves. This latter is reported to be a more mechanistic representation of P availability in the soil as compared with classical methods based on chemical extraction (Morel et al., 2021). We think that this process-based formalisms are a good compromise between biological pertinence and simplicity in the representation of P biogeochemical cycle in agro-ecosystems.

Evaluation

We tested the accuracy of the proposed formalisms through an evaluation of the model simulation of maize crop subjected to contrasting P fertilization inputs in South-Western France. The evaluation considers both soil P availability and plant P content and its partitioning (total P uptake and grain P content) as well as plant growth indicator (yield, leaf area index and biomass). This first assessment sets the stage for further evaluations notably sugarcane fertilized with both mineral fertilizers and organic waste in tropical ecosystem.

References

Cordell D, White S (2014) Life's Bottleneck: Sustaining the World's Phosphorus for a Food Secure Future. Annual Review of Environment and Resources 39:161–188. https://doi.org/10.1146/annurev-environ-010213-113300

Das B, Huth N, Probert M, et al (2019) Soil phosphorus modeling for modern agriculture requires balance of science and practicality: a perspective. Journal of Environmental Qualityl 48:1281–1294. https://doi.org/10.2134/jeq2019.05.0201

Mollier A, De Willigen P, Heinen M, et al (2008) A two-dimensional simulation model of phosphorus uptake including crop growth and P-response. Ecological Modelling 210:453–464. https://doi.org/10.1016/j.ecolmodel.2007.08.008

Morel C, Plénet D, Mollier A (2021) Calibration of maize phosphorus status by plant-available soil P assessed by common and process-based approaches. Is it soil-specific or not? European Journal of Agronomy 122:126174. https://doi.org/10.1016/j.eja.2020.126174

Impacts of cover crops on N mineral fertilization and consequences for agro-environmental performances of maize monocrop in climate change context

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Keywords : COMIFER method, fababean, nitrate leaching, GHG balance, rapeseed

Introduction

On one hand, climate change will modify nitrogen short- and long-term dynamics due to temperature and water availability variations. On the other hand, agro-ecological practices could improve cropping system resilience by allowing both adaptation and mitigation through a reduction in the use of N mineral fertilizer. In particular, cover crops (legumes or non-legumes) could considerably modify N dynamics in the soil and therefore crops N mineral fertilization needs. As a consequence, the linked management of cover crops and N fertilization could be highly altered. We used a simulation approach to assess agro-environmental impacts and mineral N fertilization changes due to introducing cover crops in the maize monocropping system, and we considered the climate change context.

Methodology

STICS was used to simulate agro-ecological practices effects on maize monocrop by targeting combinations of 3 fallow period managements (baresoil-Bs; fababean cover crop-Fb; rapeseed cover crop-Rp) and predictive balance method implementation (190 kg N. ha^{-1}.year^{-1} without modulation- Nfix or N fertilizer calculated Nbal). Cover crops were contrasted (leguminous and non-leguminous) and terminated in spring just before sowing. These six cropping systems were thus dynamically assessed over 35 continuous years, in a climate change context (2016-2050; RCP 8.5) on 5 southwestern France typical but contrasted pedoclimates (Pyrénées-Atlantiques Brunisol, Landes Podzosol, Gers Luvisol, Gers Calcosol and Haute-Garonne Calcolsol).

A modelling chain coupling decision models for sowing and fertilization date, predictive balance method (COMIFER, 2013) and STICS was developed and named STICS'TK'R. This chain allows to consider changes in sowing and N fertilization dates due to climate change but also to calculate N fertilizer needs for each year, considering climate change, and impacts of practices on soil organic matter content and mineralization from soil and crop residue. Main agro-environmental performances (sowing dates, yield, N leaching, N fertilizer amount, soil organic content (SOC), greenhouse gases (GHG) balance…) were analyzed.

Results

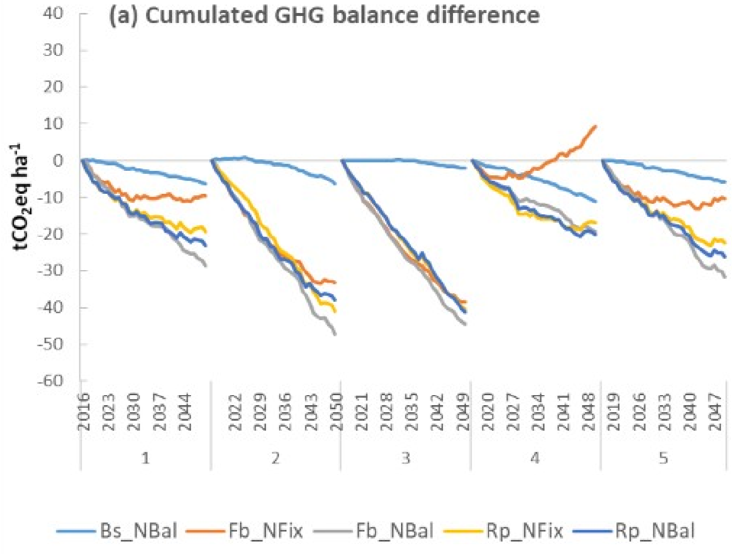
Results were driven considerably by pedoclimate context. For instance, if sowing date occurred earlier along our climate series in all sites, greater impact was simulated in Pyrenées-Atlantiques context. While maintaining yields, calculated N fertilizer need on a yearly basis substantially changes mineral N input (table 1). It allows a strong reduction of N fertilizer in combination with fababean (-27 to -89 kgN. ha^{-1}.year^{-1} on average) and on baresoil fallow period (-6 to -30 kg N. ha^{-1}.year^{-1}). Results in combination with rapeseed demonstrate very contrasted responses (+11 to -33 kg N. ha-1.year^{-1} on average depending on the site).

		Scenario					
Pedoclimate		Bs_NFix	Bs_NBal	Fb_NFix	Fb_NBal	Rp_NFix	Rp_NBal
Calcosol	Gers	190 (0)	161 (26)	190 (0)	110 (43)	190(0)	161 (20)
Luvisol	Gers		162 (37)		130 (67)		202 (47)
Podzosol	Landes		180 (14)		160 (37)		188 (20)
Brunisol	Pyrénées-Atlantiques		170 (17)		140 (30)		180 (18)
Calcosol	Haute-Garonne		163 (29)		104 (43)		158 (30)

Table 1: Average N fertilizer input (kg N. ha^{-1}.year^{-1}) according to 6 scenarios and 5 pedoclimates. Standard deviation is in brackets.

N leaching, SOC, and GHG balance dynamics also depend on pedoclimate context. Yearly cover crops allow a progressive increase in Soil Organic Content on all sites. However, intersite variability was large. For instance, values range from +76 kg C.ha^{-1}.year^{-1} to +529 kg C.ha^{-1}.year^{-1}for the Fb_NFix scenario. The GHG balance was globally enhanced by using cover crops and/or adapting N fertilization (figure 1). Not adapting N fertilization (N-fix) led to worst results than N Bal due to unnecessary higher mineral N input, NO_3 leaching and emissions as N_2O. It could even lead to worsen GHG balance on long term. For instance, cumulated GHG balance for Fb_Nfix scenario on site 4 (in Pyrenées-Atlantiques). is worse than the reference Bs-Nfix.

Figure 1: cumulative GHG balance in kg CO_2eq.ha^{-1}, expressed as the difference to the reference scenario (Scenario - Bs-Nfix).



Discussion

The modelling chain allows to explore climate change impact with a new standpoint, taking innovatively into account not only abiotic impact but also crop management changes (calendar, N fertilizer dressing). Results for maize monocrop will be discussed according to the high variability of agro-environmental impacts of our scenarios, and associated advices. The developed modelling chain will also help to explore more diversified cropping systems and agroecological practices.

References

COMIFER, 2013. Calcul de la fertilisation azotée. Guide méthodologique pour l'établissement des prescriptions locales. Cultures annuelles et prairies. www.comifer.asso.fr/images/stories/publications/brochures/BROCHURE_AZOTE_20130705web.pdf

Evaluation of strategies to reduce environmental impacts of maize production in the Quebec context using the STICS model for life cycle assessment

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Keywords: Life cycle assessment, fertilization, environmental impacts, greenhouse gases, feed crops, crop rotations, tillage practices

Introduction

Feed production is the main contributor to environmental impacts of pig and poultry production (MacLeod et al., 2013). Using lower impact raw materials or shifting to eco-friendly cultivation methods is key to reduce the impacts of animal productions, especially in the Canadian context where soybean meal has a low impact and where low diversity of feedstuffs is available. Strategies identified to reduce impacts of crop production include rationalisation of fertilization, reduction of tillage, and diversification of rotations with crops like winter wheat or spring barley, or introduction of cover crops. Life cycle assessment (LCA) is the recognized and standardized method to evaluate environmental strategies. Combined with modelling, it is a powerful tool to explore different scenarios (JRC, 2010). The objective of this study was to simulate with the STICS crop model four crop rotations with different soils and tillage practices to use some of the outputs to perform LCAs of maize produced in Quebec, Canada.

Methodology

Four crop rotations: 1) maize-soybean; 2) maize-soybean-spring barley; 3) maize-soybean with ray-grass (RG) as cover crop intercropped with the maize and 4) maize/RG-soybean-winter wheat pea and radish mix were simulated in Montérégie, Québec, Canada with the STICS crop model (version 10.0). The simulation period was from 1995 to 2015. These rotations were simulated on 3 different soils: sandy-loam, loam, and clay-loam. Three methods for pre-sowing soil preparation were considered: conventional tillage (20 cm), reduced tillage (10 cm) and no-till (tillage at 10 cm every four years). All of these modalities were crossed, producing 36 scenarios. The N_2O-N emissions, amounts of NO_3-N leached at the base of the soil profile and grain yields were averaged for soybean and maize for all the common yearsin the different rotations, to be used in the LCA.

Results

Only the simulation results for maize in the different rotations are presented. Since type of tillage had low or no impact on N_2O-N emissions and N leaching, only results for conventional tillage are presented. Grain yields simulated, in tons of dry mater, were slightly higher than regional observed averages (La Financière Agricole du Québec) for the maize-soybean, maize-soybean-barley, and maize/RG-soybean rotations, on a loam and on a clay loam. Lower yields were simulated for the maize/RG-soybean-wheat-pea/radish rotation.

The average simulated amount of cumulative NO_3-N leached at the base of the soil profile was highly variable between soil types (Figure 1a). Highest values were predicted for the sandy loam. It was lower for the most diversified rotation compared to the other rotations. This rotation also tends to reduce leaching for maize on the loam and the clay loam. The maize/RG-soybean rotation did not lead to a reduction in nitrates leaching during the maize years. However, for the entire rotation, on a loam for example, maize/RG-soybean and maize/RG-soybean-wheat-pea/radish rotation reduces cumulative nitrates leaching over 20 years by more than 500 and 600 kg.ha^{-1} respectively. Introduction of barley in the rotation increases leaching for all soil types, with a high variability between values, probably because of a longer period of uncovered soil after spring barley harvest than after other crops.

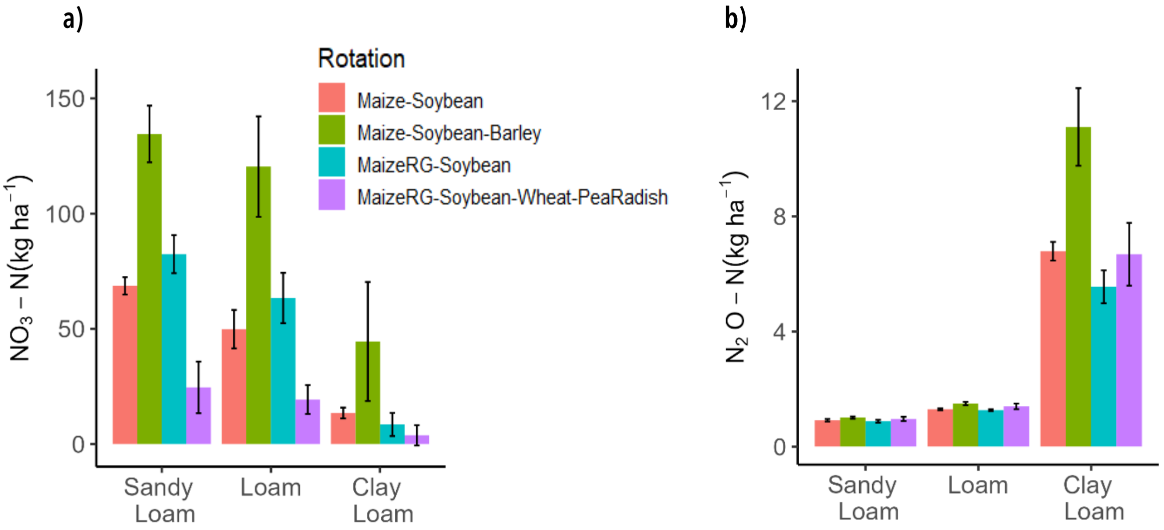

Figure 1. Effect of crop rotation on the three - years average cumulative amount of a) NO_3-N leached and b) N_2O-N emitted from soil for maize on a sandy loam, loam, and clay loam. Error bars represent standard deviation.

The average cumulative amount of N_2O-N emitted from soil was also highly variable between soil types with the highest values being predicted for the clay loam (Figure 1b). With this soil type, adding only RG to the rotation helped reduce N_2O-N emissions. With the sandy loam and the loam, simulated N_2O-N emissions were particularly low and not affected by rotations. For the entire rotation, on a clay loam, introduction of cover crop reduces N_2O-N emissions, with a total amount over 20 years of 83 kg.ha^{-1} for maizeRG-soybean and 73 kg.ha^{-1} for maizeRG-soybean-wheat-pea/radish compared to 89 kg.ha^{-1} for maize-soybean rotation.

Perspectives

Average values from the model were used to produce LCA data to evaluate environmental impacts of conventional maize production (maize-soybean rotation) and diversification practices. The LCA results for conventional production were weighted by the proportion of soil types in the region and were coherent with the existing references. Modelling results from STICS (yields, nitrates leaching) were reflected on the LCA results. Environmental benefits of diversified rotations on maize production were not observed for most contexts and impacts. However, to fully evaluate effects of these strategies, LCA at the rotation scale will need to be performed. Finally, to evaluate effects of these strategies on the impacts of animal production with the LCA method, average Quebec values will need to be produced from data obtained with STICS for other regions. Other strategies such as increased use of organic fertilizer and introduction of novel crops will also be tested in the future.

References

MacLeod, M., Gerber, P., Mottet, A., Tempio, G., Falcucci, A., Opio, C., Vellinga, T., Henderson, B., & Steinfeld, H. (2013). Greenhouse gases emissions from pig and chicken supply chains–A global life cycle assessment. Food and Agriculture Organization of the United Nations (FAO).

JRC, (2010). European Commission - Joint Research Centre - Institute for Environment and Sustainability. General guide for Life Cycle Assessment–Detailed guidance.

Session 4 - Cropping systems and climate change

Adapting STICS-MILA crop model to Yellow Rust of Winter Wheat: from calibration to simulation of climate change impacts

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Keywords: STICS-MILA, wheat, *Puccinia striiformis*, calibration, evaluation, climate change

Abstract

Future crop production depends on plant response to the increase in atmospheric CO2 and the resulting projected variations of temperature and precipitations (Hatfield et al., 2011). However attainable production also strongly depends on future biotic stresses, among which diseases are strongly dependent on abiotic constraint. STICS-MILA model was developed to generically account for pathogens interactions with crops (Caubel et al., 2012); it has been implemented and validated for brown rust (BR; *P. triticina*) of winter wheat (Caubel et al., 2017), that preferentially develops in South France.

Yellow rust (YR; *Puccinia striiformis*) rather develops in low-temperature conditions; however the appearance of invasive races like Warrior adapted to warmer climates questions the impacts of climate change on future YR epidemics (de Vallavieille-Pope et al., 2018).

In silico experiments are an efficient tool to study the effects of climate change on plant health and to evaluate the future threats of BR and YR for wheat production. We thus focused on first, calibrating STICS-MILA for YR-Wheat pathosystem, then, evaluating it thanks to independent experimental field datasets, and finally running the model under climate change scenarios in six sites of north-western France with contrasted climates.

The first step consisted in collecting in-lab, published or simulated datasets available for each phase of YR development. Then, using those datasets, the parameters of STICS-MILA generic response functions were fitted. Radiation impact on infection efficiency was added to the model, as a potential compensating factor for the effect of warm temperature (de Vallavielle-Pope et al., 2002). The parameterised model was run for BR and YR in contrasted sites to qualitatively evaluate STICS-MILA-YR in comparison to BR. Then, a global quantitative evaluation of STICS-MILA-YR was based on in-field multisite Arvalis experiments assessing disease development in fungicide-free trials. Finally, in order to simulate impacts of climate change on future YR epidemics, the model was run on six sites under future climate conditions. For future simulations, climate series were extracted from the Drias portal. Three GCM RCM model pairs were mobilized (CNRM-Aladin63, CNRM-Racmo, and EC-Earth Racmo) for two emission scenarios RCP 4.5 and 8.5. Perspectives of improvements and uses of STICS-MILA-YR will be discussed.

References

Caubel, J., Launay, M., Lannou, C., & Brisson, N. (2012). Generic response functions to simulate climate-based processes in models for the development of airborne fungal crop pathogens. Ecological Modelling, 242, 92-104. doi:10.1016/j.ecolmodel.2012.05.012

Caubel, J., Launay, M., Ripoche, D., Gouache, D., Buis, S., Huard, F., . . . Bancal, M. O. (2017). Climate change effects on leaf rust of wheat: Implementing a coupled crop-disease model in a French regional application. European Journal of Agronomy, 90, 53-66. doi:10.1016/j.eja.2017.07.004

de Vallavieille-Pope, C., Bahri, B., Leconte, M., Zurfluh, O., Belaid, Y., Maghrebi, E., . . . Bancal, M. O. (2018). Thermal generalist behaviour of invasive Puccinia striiformis f. sp tritici strains under current and future climate conditions. Plant Pathology, 67(6), 1307-1320. doi:10.1111/ppa.12840

de Vallavieille-Pope, C., Huber, L., Leconte, M., & Bethenod, O. (2002). Preinoculation effects of light quantity on infection efficiency of Puccinia striiformis and P-triticina on wheat seedlings. Phytopathology, 92(12), 1308-1314. doi:10.1094/phyto.2002.92.12.1308

Hatfield, JL et al. (2011) Climate impacts on agriculture: implications for crop production. Agronomy Journal, 103(2), 351-370, doi.org:10.2134/agronj2010.0303

Study of CO_2 and temperature effects on wheat plant growth with the STICS crop model

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Keywords: STICS, wheat, climate change, crop modelling, elevated CO2 concentration, modelled crop response

Abstract

Worldwide future crop production depends on plant response to the increase in atmospheric CO2 in interaction with projected variations for temperature and precipitations (Hatfield *et al.*, 2011). Crop models are an efficient tool to study the effects of climate change on plant growth beyond experimental results (Toreti *et al.*, 2020). For most of these models, biomass production is based on the radiation use efficiency, which is modulated by CO2 and different stress (nitrogen, water, temperature). Transpiration is also affected by CO2 besides temperature and soil water availability. To predict climate change impacts, the effects of elevated CO2 (increases in biomass production and decreases in transpiration) were implemented in most crop models. However, an important variability remains between model projections, partly due to weak understanding of the interaction of CO2 and other climatic variables such as temperature on plant functioning (Tao *et al.*, 2020; Toreti *et al.*, 2020). Hence, we focused on the STICS crop model to study cross- effects of elevated CO2 and high temperatures on wheat production to analyze the behavior of the model in the face of CO2 and temperature interactions in comparison with current experimental knowledge.

We performed several sensitivity analyses on four contrasted sites (Argentina, Australia, India, Netherlands) (Asseng, 2015) to study the impact of CO2 and temperature on different aspects of plant growth, but also to better understand the impact of the different model parameters involved in CO2 and temperature processes. We also studied the separate effect on the two processes affected by CO2 in STICS, namely RUE and stomatal conductance. This research is a preliminary study before the global sensitivity led by different modeling groups in the framework of an AgMIP exercise (Rosenzweig *et al.*, 2013).

Such an analysis enables disentangling the effects of elevated CO2 and high temperatures on different processes related to plants growth, such as yield quantity and quality, water balance or different stress indices. Eventually, the effects of CO2 and temperature on plant growth could be compared with other crop models and confronted to FACE experimental data (Ainsworth and Long, 2021), which would help identifying required improvements.

References

Ainsworth, E.A. and Long, S.P. (2021) '30 years of free-air carbon dioxide enrichment (FACE): What have we learned about future crop productivity and its potential for adaptation?', *Global Change Biology*, 27(1), pp. 27–49. Available at: https://doi.org/10.1111/gcb.15375.
Asseng, S. (2015) 'Benchmark data set for wheat growth models: field experiments and AgMIP multi-model simulations', *Open Data Journal for Agricultural Research*, 1(1), pp. 1–5. Available at: https://doi.org/10.18174/odjar.v1i1.14746.
Hatfield, J.L. *et al.* (2011) 'Climate Impacts on Agriculture: Implications for Crop Production', *Agronomy Journal*, 103(2), pp. 351–370. Available at: https://doi.org/10.2134/agronj2010.0303.
Rosenzweig, C. *et al.* (2013) 'The Agricultural Model Intercomparison and Improvement Project (AgMIP): Protocols and pilot studies', *Agricultural and Forest Meteorology*, 170, pp. 166–182. Available at: https://doi.org/10.1016/j.agrformet.2012.09.011.
Tao, F. *et al.* (2020) 'Why do crop models diverge substantially in climate impact projections? A comprehensive analysis based on eight barley crop models', *Agricultural and Forest Meteorology*, 281, p. 107851. Available at: https://doi.org/10.1016/j.agrformet.2019.107851.
Toreti, A. *et al.* (2020) 'Narrowing uncertainties in the effects of elevated CO2 on crops', *Nature Food*, 1(12), pp. 775–782. Available at: https://doi.org/10.1038/s43016-020-00195-4.

Evolution under climate change of the resilience of the services provided by the cultivated areas of the Pays de Fougères

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Keywords: dairy farms, forage production, soil C storage, climate extremes, Pays de Fougères

Introduction

As climate change is set to amplify, it is essential to anticipate its effects on dairy farms, which contribute to food production and, in the case of grassland-based systems, also mitigate greenhouse gas (GHG) emissions by storing carbon (C) in the soil of cultivated areas. This work is part of the REDELAC [14] project whose objective is to assess the impact of the future climate and to anticipate the adaptive evolution of dairy farms in the Pays de Fougères, located in the Brittany region of France. The latest is an agricultural area with a soil and climate favourable to production. It has a territorial Climate Air Energy Plan (TCAEP), one of whose objectives is to reduce current agricultural GHG emissions by 40% by 2050. In this work, we aim to answer the following questions: what is the evolution of forage production and soil organic C (SOC) storage on the scale of the dairy farms studied? Is this evolution similar between time horizons and between farms? Are the animals' feed requirements being met less frequently, and in what proportion? What factors influence these trends? How sensitive are those evolutions to local climate and soil conditions and to future climates?

Material and methods

The expected evolution of climate was first described using indicators calculated for different future climate scenarios. As climate change is likely to affect the services rendered by dairy farms differently according to their forage system, we compared three typical dairy farms, distinguished in particular by the proportion of grass and maize in the dairy cows' diet. The use and management of cultivated areas of these farms were then described and simulated under climate change using the STICS model (Beaudoin et al., 2023) and the diversity of the region's soil and climate conditions. Different future climates were used as input to STICS and simulations were carried out over 30 years, comparing 4 time horizons: 1976-2005, 2021-2050, 2041-2070 and 2071-2100. The initialization of SOC took into account the use of cultivated land (higher initial SOC stocks under permanent grassland than under arable/temporary grassland rotations, with a higher mineralizable fraction) but was the same for each time horizon. Forage stocks and SOC evolution at farm level were calculated from the areas (assumed constant in our simulations) allocated to each crop in each rotation and respectively from the yields and SOC evolution simulated by STICS. Indicators derived from Picasso et al. (2019) were calculated to characterize the evolution of forage production resilience: i) the number of crisis years, *i.e.* when forage stocks were below the herd's feed requirements, as well as ii) the proportion of feed requirements covered in those years, iii) the average value and stability of forage production in other years (stocks ≥ requirements). A statistical analysis was carried out and links were sought between the evolution of the services studied and the factors (climate, nature of the forage system, time horizon, processes involved) that could explain their evolution.

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Results and discussion

Preliminary results show that fodder stocks are on the rise (+20 to +40% by 2100) with less risks for animals' feed requirements not to be met (Fig. 1). Climatic conditions that lead to a crisis year differ according to the nature of the stock (corn silage, grazed grass, grass silage, hay, etc.). STICS simulates a negative effect of climate change on the average SOC stock evolution of each farm, as well as a slight increase in N_2O emissions. The trend towards SOC loss is less marked for the grass-based dairy farm which is the only one with a positive SOC storage up to 2070. The increase in SOC inputs associated with higher forage production is indeed offset by an increase in the mineralization of SOC due to higher temperatures.

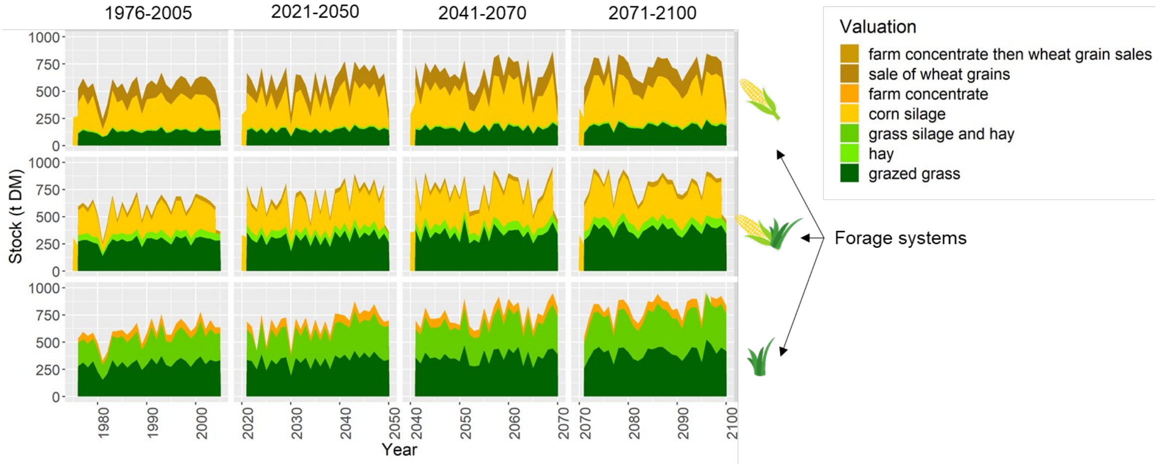

Figure 1. Evolution of the feedstocks produced by the cultivated area of each simulated dairy farm

Conclusions and perspectives

While the Fougères region's food security does not appear to be compromised, targets for reducing the agricultural sector's carbon footprint set out in the Pays de Fougères' TCAEP may not be achieved. A change in dairy farming towards a greater proportion of grass in the animals' diet could be desirable to limit the negative impacts of climate change on the SOC stock. However, these results need to be confirmed, as they currently only concern part of the territory and one climate scenario.

References

Beaudoin N., Lecharpentier P., Ripoche D., Strullu L., Mary B., Leonard J., Launay M., Justes E., 2023. STICS soil-crop model. Conceptual framework, equations and uses, Versailles, Éditions Quæ. http://doi.org/10.35690/978-2-7592-3679-4

Picasso, V. D., Casler, M. D., & Undersander, D., 2019. Resilience, Stability, and Productivity of Alfalfa Cultivars in Rainfed Regions of North America. Crop Science, 59(2), 800-810. https://doi.org/10.2135/cropsci2018.06.0372

Spring barley yield and potential northward expansion under climate change in Canada

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Keywords : crop models; DNDC, DSSAT, STICS; spring barley; climate change

Introduction

In Canada, the extended growing season due to climate change is expected to increase the yield of many crops and move their growth range northward. Spring barley, one of the main annual crops produced in Canada, is well suited for northern regions since it has excellent cold tolerance and early ripening. Thus, it may not benefit from climate change as much as other crops better suited for the warmer climate, but its geographical expansion could shift to the north. The objective of this study was to assess the potential impacts of climate change on barley yields across Canada including regions where barley is currently produced and northern regions where it may be grown in the future.

Materials and methods

Three crop models, DNDC (Smith et al., 2020), DSSAT (Hoogenboom et al., 2019) and STICS (Beaudoin et al., 2022) and 18 climate scenarios (6 climates models and 3 SSP) were used to simulate the effect of climate change on potential and rainfed spring barley yields for 32 locations across Canada. Simulations were performed from 1981 to 2100 under potential (non-water and non-nitrogen limited) and rainfed conditions (non-nitrogen limited). Simulations results were presented for three periods: reference (1981-2010; Ref)), near future (2021-2050; NF) and distant future (2051-2080; DF).

Results and discussion

For the currently planted spring barley regions characterized by a humid summer in Eastern Canada (growing season precipitation > 500 mm), potential and rainfed yields were projected to slightly increase in the future (<+0.2 t ha^{-1}; Figure 1). In western regions (Canadian Prairies) where precipitation amount is lower (growing season precipitation < 500 mm), changes in the potential yield varied slightly (-0.1 to +0.2 t ha^{-1}; figure 1a) while the rainfed yield was projected to increase (0.2 to 1.0 t ha^{-1}; figure 1b) mainly due to a reduction in water stress under elevated CO_2.

Finally, in northern regions where future expansion may occur, projected yield increases were generally large (up to 2.8 t ha^{-1} for potential yield), but the risk of crop failure usually remained high. Our findings suggest that future climate change will present both opportunities and regionalized risks for spring barley producers with the potential to further expand barley production northward.

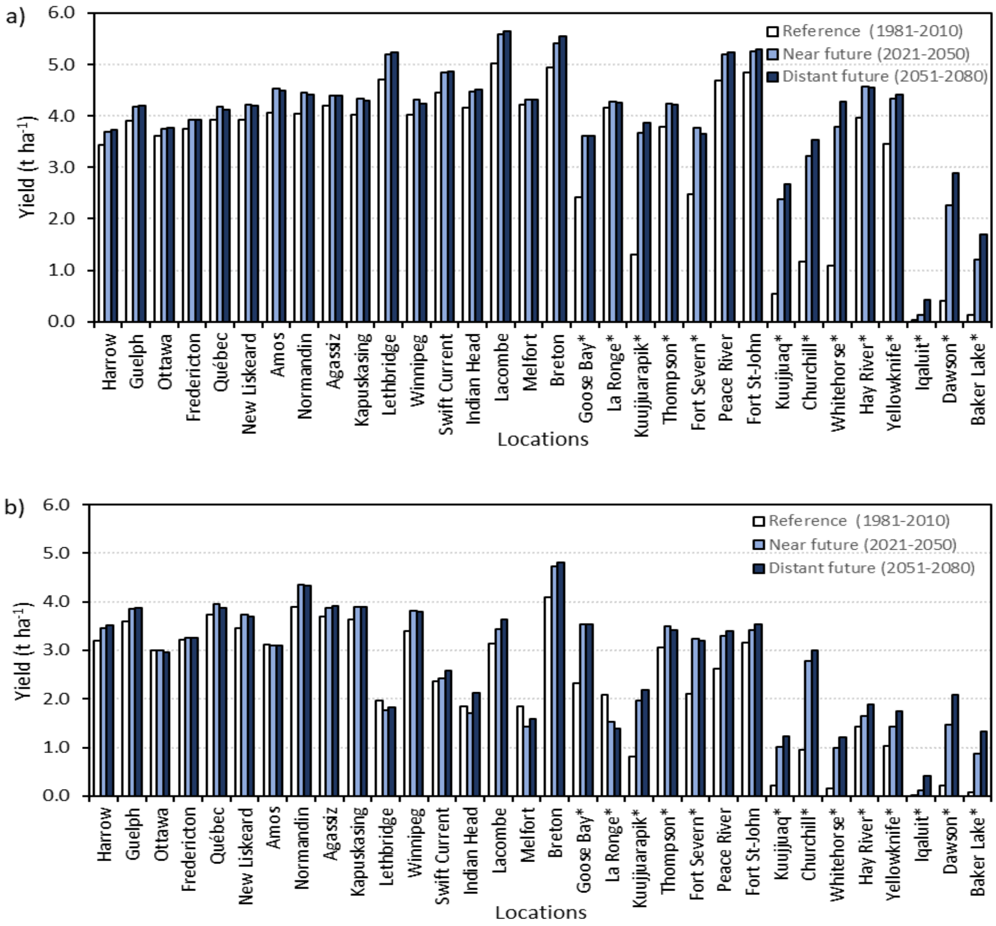

Figure 1. Average a) potential and b) rainfed yield across the different periods studied. Locations are ordered by latitude from 42.0 for Harrow, to 64.3 for Baker Lake. Locations with an asterisk (*) are northern locations where barley is not grown currently.

References

Beaudoin N., Lecharpentier P., Ripoche D., Strullu L., Mary B., Leonard J., Launay M., Justes E., eds. 2022. STICS soil-crop model. Conceptual framework, equations and uses, Versailles, Éditions Quæ

Hoogenboom, G., Porter, C.H., Boote, K.J., Shelia, V., Wilkens, P.W., Singh, U., White, J.W., Asseng, S., Lizaso, J.I., Moreno, L.P., Pavan, W., Ogoshi, R.M., Hunt, L.A., Tsuji, G.Y., Jones, J.W., Usda-Ars, U., 2019. The DSSAT crop modeling ecosystem, in: Boote, K.J. (Ed.), Advances in Crop Modeling for a Sustainable Agriculture. Burleigh Dodds Science Publishing, Cambridge, United Kingdom, pp. 173-216.

Smith, W., Grant, B., Qi, Z., He, W., VanderZaag, A., Drury, C.F., Helmers, M., 2020. Development of the DNDC model to improve soil hydrology and incorporate mechanistic tile drainage: A comparative analysis with RZWQM2. Environmental Modelling and Software 123.

Modeling agroecological intensification in the tropics with the Stics model – lessons learned and way forward

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The year 2023 will likely be the hottest ever recorded on our planet. Adapting to climate change and climate extremes is increasingly becoming a day-to-day concern for African farmers, along with food security and income issues. Agricultural adaptations like varietal choice and fertilizer doses have deserved great attention from the crop modeling community, and are overall well accounted for by crop models. Agroecological practices, for example residue mulching, rotation and intercropping with legumes and application of organic amendments offer great potential to adapt to climate change. Yet, they have deserved less attention when it comes to the modeling of their performance in tropical context. In this abstract, we describe a collective research effort to update and test the Stics soil-crop model to account for the impact of agroecological practices on cropping system performance in the tropics. We built on multiple years of measurements in contrasting experimental sites from cool to warm, semi-arid to sub-humid subtropical environments, in Senegal, Zimbabwe, Mali, Burkina Faso, Kenya, Brazil and Madagascar. We assessed the skills and pitfalls of the model to simulate i) new cereal and legume crops ii) cereal-legume intercropping, iii) crop residue decomposition and feedbacks on crop growth and iv) crop residue mulching.

We calibrated a new set of parameters for tropical maize (Falconnier et al., 2020), sorghum (Traoré et al., 2022, Ganeme et al., in revision), millet (Sow et al., forthcoming), rice (Ranaivoson et al., 2022), and legumes like cowpea (Traoré et al., 2022, Ganeme et al., in revision) and groundnut (Civil, 2022). Model accuracy (rRMSE) for end-of-season variables like aboveground biomass and grain yield was in the range of 20 to 50%. The scrutiny of in-season soil water and plant leaf area index (LAI) indicated that water stress was often underestimated, possibly because of underestimation of soil evaporation, and underestimation of the impact of water stress on LAI. Cereal yield with no fertilizer input was also not well reproduced, because of inadequate simulation of the soil organic matter mineralization that provides the mineral N required for plant growth. We are now working on implementing a new evaporation function into the model (i.e. new Stics modeling branch, Diop et al., this conference) to account for the specificities of warm tropical environments (i.e. the topsoil does not necessarily reach field capacity after a rainfall event). Our objective is also to implement a new mineralization function that is specific to the tropical context and allows for a better simulation of in-season soil organic matter mineralization. For legumes in particular, new data on nitrogen fixation will be used to test the accuracy of model simulation with the current set of calibrated plant parameters.

We assessed STICS ability to reproduce the performance of cereal-legume intercropping. STICS simulated the observed loss in legume yield due to competition for light with the taller cereal (Traoré et al., 2022). Competition for water (in relation to root growth) and nitrogen (in relation to N fixation of the legume) is being investigated with new observations currently processed. The impact of intercrops' relative densities, sowing date, fertilization, and the interaction with climate on intercropping performance and stability, is being investigated through sensitivity analysis (Traoré et al., in revision, de Freitas et al., this conference, Ganeme et al., in revision).

We evaluated STICS skills in reproducing the decomposition of organic amendment and the feedbacks on crop growth through provision of mineral N. We found that parameterizing the C/N ratio of legumes and keeping the default value of other decomposition parameters was sufficient to simulate accurately legume residues decomposition and N provision to the subsequent rice crop (Ranaivoson et al., 2022). We also found that STICS reproduced well the observed feedbacks between declining soil organic carbon and declining yield. In comparison, these feedbacks were not reproduced by all 16 soil crop models tested in a study of the AgMIP low input systems group (Couëdel et al, in revision). The impact of clay and pH on soil organic matter mineralization, as currently implemented in the model, leads to inaccurate long-term changes in soil organic carbon. Other parameters related to organic amendment decomposition need to be recalibrated in order to accurately simulate the impact of the incorporation of these residues on changes in soil organic carbon. As a way forward, we advocate for the need to develop a new mineralization function to better account for long term soil organic carbon changes.

Crop residue mulching helps reduce evaporation and can be a key adaptation strategy. Earlier simulation study showed that soil temperature under mulch (Balde, 2011) was not adequately represented, leading to poor simulation of soil organic matter mineralization. This issue is currently being investigated with new data collected in sub-humid Zimbabwe so that new formalisms can be implemented into the model (new Stics modelling branch, Diop et al., this conference).

This on-going work to assess and update Stics to a range of agroecological practices is very much open to new collaboration – please come and join us! This initiative is critical as it will improve our ability to design and test the much-needed adaptation strategies for smallholder farmers of the tropics.

References

Balde, A.B., 2011. Analyse intégrée du partage des ressources (eau , azote et rayonnement) et des performances dans les systèmes de culture en relais sous semis direct en zone tropicale subhumide. Thèse. SUPAGRO Montpellier.

Civil, J.-A., 2022. Modélisation de la croissance et du rendement de l'arachide (Arachis hypogaea L.) en milieu tropical : cas du bassin arachidier du Sénégal. Institut de Recherche pour le Développement (IRD), CNRS IRD – UMR-242.

Couëdel, A., Falconnier, G., Corbeels, M., Adam, M., Cardinael, R., Boote, K., Justes, E., Smith, W., et al. Long term soil organic carbon and crop yield feedbacks differ between 16 soil-crop models in sub-Saharan Africa (under review in European Journal of Agronomy).

Falconnier, G.N., Corbeels, M., Boote, K.J., Affholder, F., Adam, M., MacCarthy, D.S., Ruane, A.C., et al., 2020. Modelling climate change impacts on maize yields under low nitrogen input conditions in sub-Saharan Africa. Glob. Chang. Biol. 1–23.

Ganeme, A., Larue, F., Traoré, S., Adam, M. Potentiel d'adaptation des associations sorgho-niébé au changement climatique en zone soudano-sahélienne du Burkina Faso? (submitted to Cahier d'Agriculture)

Ranaivoson, L., Falconnier, G.N., Affholder, F., Leroux, L., Autfray, P., Muller, B., Auzoux, S., Ripoche, A., 2022. Can green manure contribute to sustainable intensification of rainfed rice production in Madagascar? F. Crop. Res. 289, 108711.

Traoré, A., Falconnier, G.N., Ba, A., Sissoko, F., Sultan, B., Affholder, F., 2022. Modeling sorghum-cowpea intercropping for a site in the savannah zone of Mali : Strengths and weaknesses of the Stics model. F. Crop. Res. 285.

Traoré, A., Falconnier, G., Couëdel, A., Sultan, B., Chimonyo, V., Adam, M., Affholder, F. Sustainable intensification of cereal-based cropping systems in semi-arid sub-Saharan Africa: intercropping or combining cereal and legume sole crops? (under rev. F. Crop. Res.)

Sow, S., Senghor, Y., Sadio, K., Vezy, R., Roupsard, O., Affholder, F., N'dienor, M., Clermont-Dauphin, C., Gaglo, E., Ba, S., Tounkara, A., Balde, A., Agbohessou, Y., Seghieri, J., Nourou Sall, S., Couedel, A., Leroux, L., Diate, D., Falconnier, G. Calibrating the STICS soil-crop model to explore the impact of agroforestry parklands on millet growth (under review in F. Crop. Res.)

Potential production of energy cover crop in France: consequences on food crop production and environmental impacts based on scenarios simulation at high resolution.

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Keywords : multi-services cover crop; biogas; climate change mitigation; carbon storage; nitrogen; GHG balance

Introduction

Cover crops could be considered either as multi-services crops (MSCC) (Justes at al, 2017) that are included in rotation for different agronomical purposes (N leaching limitations, storage of Carbon …) or as raw materials used to produce biogas in fermenter by an anaerobic digestion process (AD)). In this latter case, we considered them as energy cover crop (ECC). Some European countries are exploring the idea of replacing dedicated crops with ECC for biogas production, accompanied with specific regulation measures in order to avoid competition with food crops for land use and to sustain crop services such as limitation of N leaching. In France, some studies (ADEME 2018, 2021) gave an estimation of 18 and 23 Mt covering 11 to 30% of our gas needs by 2050 but based on simple assumptions and coarse calculations. We present here the methodology and the results of the chapter 5 of C. Launay's phD (Launay 2023) about the estimation of the potential production of ECC at France scale and the impacts on food production and on environment. One of the originality of this work has consisted in the design of a modelling chain combining different models in order to represent the different processes from field to energy production. Then, we applied it at France scale.

Material and method

We first used the method and the datasets of Launay et al. (2021a, b) to set up the basis of the modeling chain. They described at the scale of a few km2 the current French cropping systems (crop successions and crop management) and the associated pedo-climatic conditions in order to simulate them for 30 years with the STICS crop model. To better adapt N mineral fertilization, we added the N balance method, considering organic or mineral fertilizer use (COMIFER 2013). In both scenarios with AD, we added the AD model SYS-Metha (Bareha et al. 2021b) into the modeling chain to transform harvested cover crop into biogas and digestate which was spread on the following crop as fertilizer. In addition, given the poor results of STICS on ammonia volatilization following organic fertilizer applications (Moinard 2021), we used the ALFAM2 model in parallel to estimate this output. Figure 1 gives the architecture of the modelling chain, and the process simulated by each component. The whole simulation chain was coded on R version 4.0.3 using SticsRpack.

We developed the experimental plan on 4 scenarios: i) *Baseline* with current cropping systems from the 4per1000 project (Launay et al., 2021), ii) *Multi-services cover crops extension*: generalization of the use of MSCC to produce different ecosystem services in addition to N leaching reduction, such as providing N to the following crop with legumes or increasing soil carbon storage with grasses, iii) *Energy cover crops*: Introduction of AD and ECC. The ECC species were chosen for their high biomass production potential; iv) *Energy crops extension:* Modification of the crop rotations and crop precocity to integrate more ECCs to produce more biogas.

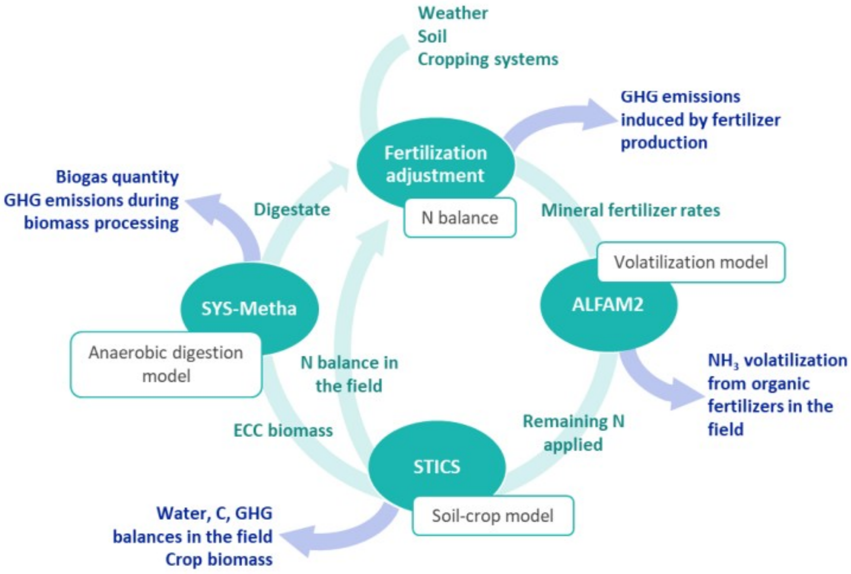

Figure 1: The modelling chain. Includes 4 models (turquoise ovals). The loop is repeated for each crop in the succession until the end of the 30 years. At the end of each loop, the outputs are saved and used in the next loop to ensure the continuity of the N, C and water balances.

Results

We based the analyses of the results on two dimensions: i) Production of biomass (cover crops production of biomass, exportation of ECC biomass, main crops production of biomass), ii) Environmental impact on non-livestock systems (climate change mitigation, air quality improvement, water resource saving, reduction of groundwater eutrophication). Figure 2 summarizes the results. ECCs can be a major source of energy in France: from 17 to 115 TWh. They are indeed a lever for climate change mitigation, despite their fertilization and the associated increase in N2O emissions, due to the substitution of fossil gas and the storage of C in the soil. However, the additional biomass production and fertilization are likely to be at the expense of air quality and water availability. They still reduce nitrate pollution but to a lesser extent than some MSCC species. As for of food production, harvest dates and species of ECC should be chosen carefully to avoid pre-emptive competition with the following crop while still producing enough biomass for biogas.

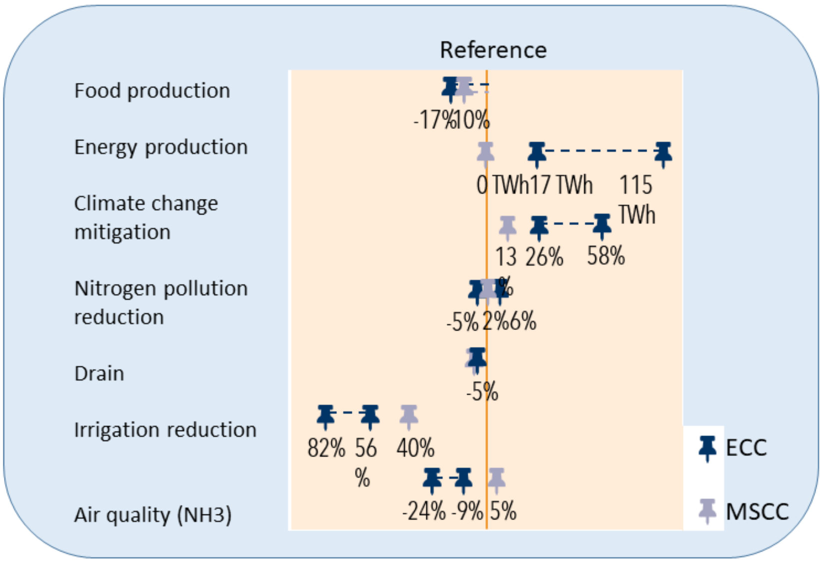

Figure 2: Synthesis of the results

Discussion

This original work demonstrates the interest of introducing cover crops in crop rotations to contribute to energy production. This generic modelling chain could be improved by updating more dynamically the information concerning cropping systems and agronomic practices at France scale.

References

ADEME (2018) Un mix de gaz 100 % renouvelable en 2050 ? Rapport. https://librairie.ademe.fr/energies-renouvelables-reseaux-et-stockage/1548-mix-de-gaz100-renouvelable-en-2050--9791029710476.html?search_query=gaz&results=488
ADEME (2021) Transition(s) 2050. Rapport, ADEME Edit
Bareha Y, Affès R, Buffet J, Girault R (2021a) SYS-Metha : Outil de prédiction des flux d'azote et de carbone sur les filières de méthanisation et des propriétés des digestats. https://doi.org/10.15454/U4S6OF
COMIFER (2013) Calcul de la fertilisation azotée - Cultures annuelles et prairies, COMIFER
Justes E., Richard G. Contexte, concepts et définition des cultures intermédiaires multi-services. Innovations Agronomiques, 2017, 62, pp.1-15. https://hal.science/hal-01770348
Launay C, Constantin J, Chlebowski F, et al (2021a) Estimating the carbon storage potential and greenhouse gas emissions of French arable cropland using high-resolution modeling. Glob Chang Biol 27:1645–1661. https://doi.org/10.1111/gcb.15512
Launay C, Constantin J, Raynal H, et al (2021b) Etude 4pour1000 : Données modèle STICS
Launay C. Insertion of energy cover crops in cropping systems in France: multi-scale assessement of potential production and water—nitrogen—carbon impacts. PhD . 2023
Moinard V, Levavasseur F, Houot S (2021) Current and potential recycling of exogenous organic matter as fertilizers and amendments in a French peri-urban territory. Resour Conserv Recycl 169:105523. https://doi.org/10.1016/j.resconrec.2021.105523

Increasing soybean production in Europe: impact on cropping systems and environment

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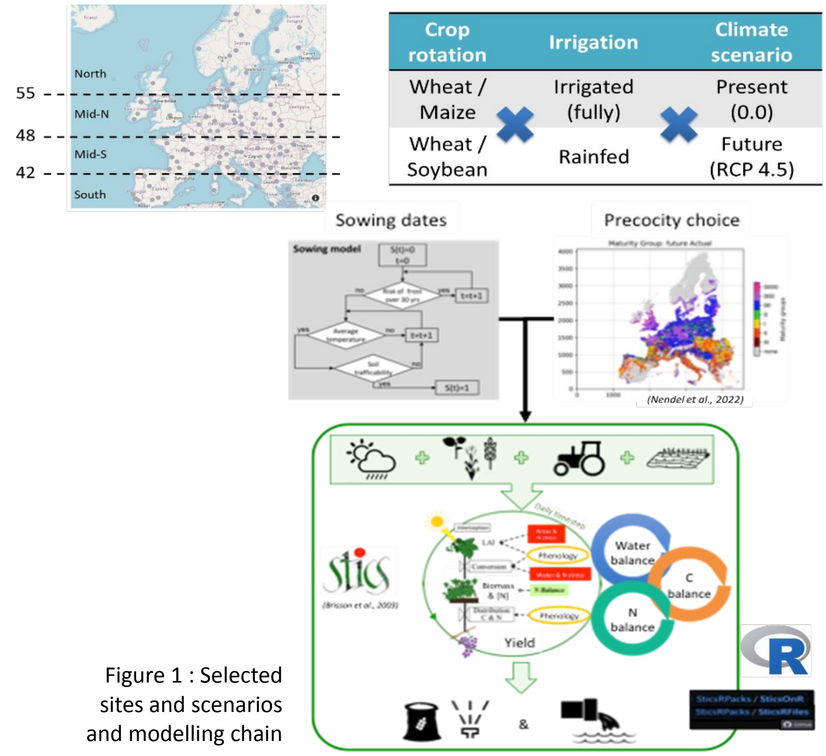
The introduction of soybean in agricultural cropping systems is a promising strategy for crop rotation diversification and protein self-sufficiency in Europe. Soybean produces plant proteins for human or animal consumption, while reducing the needs for chemical fertilizers through nitrogen symbiotic fixation. Replacing maize with soybean could have positive effects on the environment by reducing greenhouse gas emissions. The objectives of our study are : i) to assess the potential yield of soybean over Europe and the yield gap with limited water and ii) to quantify the environmental impacts (water drainage, nitrate leaching, C storage and GHG balance) of replacing maize by soybean at the crop rotation scale.

Material & methods

The method consisted in selecting 100 grid cells of **25x25 km²** across Europe based on the European Soil Database *(Hiederer, 2013) and* on the climate dataset proposed by *Webber et al. (2018)* with a baseline (1985–2010 - JRC Agri4Cast database v 2.0) and a climate change scenario (using climate Models GCM: MPI-ESM-MR).

Eight scenarios were designed combining 2 crop rotations, 2 irrigation options and 2 climate scenarios (fig 1). Wheat and maize received 190 kgN/ha/yr of fertilizer while soybean was always unfertilized.

We simulated sowing dates and precocity group for maize & soybean based on decision rules according to the climate of each site and year. Then, simulations were run over 25 years with the crop model STICS 9.2 *(Brisson et al., 2003) for each scenario on each site.*



Crop rotation		Irrigation		Climate scenario
Wheat / Maize	✖	Irrigated (fully)	✖	Present (0.0)
Wheat / Soybean		Rainfed		Future (RCP 4.5)

Figure 1 : Selected sites and scenarios and modelling chain

The GHG balance was calculated as in Launay et al., (2021)*:

$$GHG\ balance = 296 \times 44/28\ (direct\ N_2Oe + indirect\ N_2Oe) - 44/12 \times C\ storage + 5.34 \times N\ fertilizer$$

* *direct N_2Oe = 1% fertilizer & indirect N_2Oe = 0.075% of N leached + 1% of N volatilization for fertilizer*

We then analysed the potential yield and associated yield gap of soybean by latitude group and the environmental impact of soybean introduction (water, N, C and GHG).

Results and discussion

Potential yield of soybean increases with climate change, except in the South where it decreases slightly. At the same time, actual yield increases in the northern half of Europe and decreases in the southern half. As a result, the yield gap slightly increases from 2 to 10%, except in the North of Europe where it decreases by 3%. Introducing soybean instead of maize reduces irrigation requirement from 10 to 50% depending on the latitude group. Irrigation increases strongly from North to South whatever the climate scenario, and it globally increases a little in the future (RCP 4.5).

The study found that, in both current and future climate, the introduction of soybean in the rotation: i) increased water drainage, particularly in rainfed systems; ii) reduced nitrate leaching and N_2O emissions related to fertilizer, iii) decreased soil C storage due to lower residue returned by soybean, compared to maize and iv) decreased GHG balance, reducing the environmental impact of agriculture.

References

Brisson et al., 2003 – doi10.1051/agro
Hiederer, 2013 - Report EUR 26082 EN
Launay et al., 2021 – doi10.1111/gcb.15512
Nendel et al., 2022 – doi10.1111/gcb.16562
Weber et al. 2018 –doi10.1038/s41467-018-06525-2

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Session 5 – Intercropping

Modeling Key Interactions in Bi-Specific Intercropping Systems: Enhancing the STICS Soil-Crop Model for Sustainable Agriculture

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Keywords: species mixture; spatial design; wheat; pea; faba bean; sunflower; barley; soybean

Introduction

The demand for sustainable agriculture has led to increased interest in intercropping as a way to reduce the use of chemicals and maximize production. However, accurately predicting the benefits of intercropping is challenging due to the complex interactions between different plant species, the environment, and agricultural practices. While soil-crop models are useful for understanding these interactions throughout the growing season, there are few models that can accurately simulate intercropping systems. A first version of STICS was designed to simulate bi-specific intercrops (Brisson et al., 2004).

Main

In this study, we present a set of simple and versatile formalisms for designing a model that can simulate key interactions in bi-specific intercropping systems, including processes such as plant development, light interception, plant growth, nitrogen and water balance, and yield formation, considering factors like management practices, soil conditions, and climate. We evaluated the effectiveness of these formalisms by integrating them into the STICS soil-crop model and comparing the results with observed data from various intercropping systems involving cereal and legume mixtures, such as Faba bean-Wheat, Pea-Barley, Soybean-Sunflower, and Wheat-Pea mixtures. Our findings demonstrate that the proposed equations and guidelines offer a comprehensive simulation of soil-plant interactions in different types of bi-specific intercrops. The new STICS model consistently performed well and proved to be versatile across a range of spring and winter intercrops of arable crops, with prediction errors of 25% for maximum leaf area index, 23% for shoot biomass at harvest, and 18% for grain yield (Vezy et al., accepted in ASD).

Conclusion

The complete set of formalisms has been developed and published for simulating bi-specific intercropping systems and integrated into the STICS soil-crop model (Vezy et al. 2021; Vezy et al. accepted in ASD). The new version of STICS improved for intercropping, with its emphasis on being versatile, accurate, simple, and easy to parameterize, is well-suited for assisting researchers in virtually assessing sustainable intercrop systems that are suitable for local conditions, thus contributing to the agroecological transition.

References

Vezy, R., Munz, S., Gaudio, N., Launay, M., Lecharpentier, P., Ripoche, D., Justes, E. Modelling intercrops functioning using STICS model to advance the design of innovative agroecological systems. Accepted in Agronomy for Sustainable Development.

Vezy, R., Munz, S., Gaudio, N., Launay, M., Lecharpentier, P., Ripoche, D., Justes, E. (2022). Modelling intercrops functioning to advance the design of innovative agroecological systems. Research Square preprint doi: https://doi.org/10.21203/rs.3.rs-1930394/v1; version posted August 18

Intercropping cereals and legumes to stabilise yield in the tropics: evaluation of the STICS soil-crop model to simulate bi-specific intercrops

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Keywords : intercropping, resilience, intensification

Introduction

Intercropping cereals and legumes is a common practice in tropical regions. A recent review (Namatsheve et a., 2020) showed a good agreement in the literature about its positive effect on total grain yield and aboveground biomass compared to sole cropping under low-input farming. Intercropping is expected to increase and stabilise yield thanks to i) complementarity in using light, water and nitrogen, ii) microclimate effects, and iii) contrasting sensitivities of cereals and legumes to biotic and abiotic stresses. However, this claim has not been supported by experiments on long historical weather series. Yields in Sub-Saharan Africa are low because of low nutrient inputs. Sustainable intensification with addition of mineral fertiliser can increase cereal yield in intercropping systems. Fertilisation management in intercropping is more complex than in sole cropping as it modifies competition and complementarity between crops. Soil-crop models are useful to explore the impact of contrasting N fertilisation and to test long term interannual variability of yield for contrasting sites, for broader conditions than those tested in field experiments. This work first aimed to evaluate the performance of the STICS model improved for intercropping (Brisson et al., 2004, Beaudoin et al., 2023) in simulating cereal-legume intercrops in tropical regions. Then, the hypothesis that intercropping increases and stabilises grain yield in the face of interannual rainfall variability was tested. The effects of fertilisation and annual rainfall on these benefits of intercropping were estimated.

Methods

This work was based on experimental data collected in Brazil, Mali, Senegal and Burkina Faso. Bi-specific intercropping and sole crops of different combinations of cereals - maize, sorghum, millet - and legumes - pigeon pea and cowpea were compared. Once calibrated to reproduce field observations, the STICS soil-crop model was used to perform simulations on historical climates and explore the effect of year-to-year variability on model outputs. A sensitivity analysis assessing the effect of N fertilisation on the cereal was performed. The benefits of intercropping were assessed by comparing productivity and yield stability of intercrops with cereal sole cropping. The calculation of the partial Land Equivalent Ratio (pLER) of grain yield, aboveground biomass, cumulative intercepted radiation, cumulative soil nitrogen uptake and nitrogen fixation for cereals and legumes for each N treatment, allowed to understand the complementarities and competitions in the intercropping.

Results

The model calibration provided good agreement between observed and simulated grain yields for cereal and legume sole cropping as well as for intercropped cereals. The simulation efficiencies (Ef) were greater than 0.74 and the rRMSE were less than 35%. Model accuracy was lower for intercropped legumes (Ef = 0.58, rRMSE =62%), mainly due to overestimation of low cowpea grain yields. Observed complementarity and competitions were in overall well reproduced by the model, through an accurate simulation of cereal and legume pLER across all sites and conditions.

The twenty-year virtual experiment showed that unfertilised intercropping did not significantly reduce energy yield compared to cereal sole cropping, but had higher protein yield (except in Senegal in both cases) and higher energy and protein yield stability compared to cereal sole cropping in Sub-Saharan Africa. The benefits of intercropping in terms of productivity and yield stability decreased with fertilisation in Sub-Saharan Africa. Analysis of grain yield at all sites revealed that the relative productivity gain in intercropping compared to cereal sole cropping increased as a function of annual rainfall. This effect was significant in unfertilised conditions. However, in fertilised conditions this effect was no longer significant and was due to other site-specific effects.

References

Beaudoin, N., Lecharpentier, P., Ripoche-Wachter, D., Strullu, L., Mary, B., Léonard, J., … & Justes, E. (2023). STICS soil-crop model: conceptual framework, equations and uses.

Brisson, N., Bussiere, F., Ozier-Lafontaine, H., Tournebize, R., & Sinoquet, H. (2004). Adaptation of the crop model STICS to intercropping. Theoretical basis and parameterisation. *Agronomie*, 24(6-7), 409-421.

Namatsheve, T., Cardinael, R., Corbeels, M., & Chikowo, R. (2020). Productivity and biological N 2-fixation in cereal-cowpea intercropping systems in sub-Saharan Africa. A review. *Agronomy for Sustainable Development*, *40*, 1-12.

The first calibration and evaluation of the STICS soil-crop model on chickpea-based intercropping system under Mediterranean conditions

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Keywords: Chickpea, Crop diversification, N fertilization, Optimization, Model efficiency, Temporal dynamic

Introduction

Soil-crop models are commonly used to assess the combined effects of cropping patterns, soil management and climate on agro-environmental indicators. They provide a wide range of predictive data that can be used to design and evaluate new cropping systems. However, intercropping modelling is still at an early stage, particularly for cereal legume-based intercropping systems.

Methodology

The STICS model (v 9.2) was calibrated for the first time on chickpea, grown under different nitrogen (N) levels during two cropping seasons (2018/2019 and 2019/2020) under Algerian sub-humid conditions. This calibration allowed us to simulate a wide range of agronomic scenarios (climate, N fertilisation and cropping system) to improve the durum wheat-chickpea intercropping management. A sequential optimization method was used to estimate 37 parameters.

Results

STICS predicted Leaf Area Index (LAI), Above Ground Biomass (AGB) N uptake well for both intercropped and sole cropping, with good model efficiency (EF ranging from 0.62 to 0.93). Furthermore, the model correctly predicted grain yield with a small error ($NRMSE \leq 13\%$) for the wheat crop ($EF \geq 0.50$), although it was less accurate for the chickpea crop ($EF \leq 0.24$ and $NRMSE \leq 21\%$). STICS predicted root depth well under our field study conditions ($EF \geq 0.65$ and $NRMSE \leq 37\%$). For soil output variables, the model accurately approximated soil water content with a satisfactory model efficiency ($EF \geq 0.65$ and low relative error ($NRMSE \leq 8.8\%$), especially for monocropped and intercropped chickpea. Soil N stocks were less correctly predicted ($EF \leq 0.28$) with a large relative error ($NRMSE \geq 56\%$) in a monocropping system, but moderately predicted ($EF \leq 0.44$) in an intercropping system. In the two contrasting years and N application conditions of this study, the model reproduced the temporal dynamics well for both plant and soil outputs with low simulation errors. The dynamics of soil water content were also effectively reproduced across all N application rates and cropping years, with an RMSE of 27 mm (10%).

Conclusion

The current study provides the first calibration for chickpea sole cropping and an evaluation for durum wheat-chickpea intercropping, allowing the STICS model to be used to simulate scenarios of innovative cropping practices based on crop diversification (grain legumes and cereals) and N fertilizer management.

References

1- Glaze-Corcoran, S., Hashemi, M., Saghpour, A., Jahnazad, E., Afshar, R.K., Liu, X., Herbert, S.J., 2020.Understanding intercropping to improve agricultural resiliency and environmental sustainability. Adv. Agron. 162, 199–256. https://doi.org/10.1016/bs.agron.2020.02.004.

2- Peoples, M.B., Hauggaard-Nielsen, H., Huguenin-Elie, O., Jensen, E.S., Justes, E., Williams, M., 2019. The contributions of legumes to reducing the environmental risk of agricultural production. In Agroecosystem Diversity; Academic Press: Cambridge, UK, pp. 123–143. https://doi.org/10.1016/B978-0-12-811050-8.00008-X.

3- Rodriguez, C., Carlsson, G., Englund, J. E., Flöhr, A., Pelzer, E., Jeuffroy, M. H., Makowski, D.,& Jensen, E. S., 2020. Grain legume-cereal intercropping enhances the use of soil-derived and biologically fixed nitrogen in temperate agroecosystems. A meta-analysis.European Journal of Agronomy, 118, 126077.https://doi.org/10.1016/j.eja.2020.126077.

4- Brisson, N., Launay, M., Mary, B., Beaudoin, N., 2008. Conceptual Basis, Formalisations and Parameterization of the Stics Crop Model.Editions Quae.

5- Falconnier, G.N., Journet, E.-P., Bedoussac, L., Vermue, A., Chlébowski, F., Beaudoin, N., Justes, E., 2019. Calibration and evaluation of the STICS soil-crop model for faba bean to explain variability in yield and N2 fixation. Eur. J. Agron. 104, 63–77. https://doi.org/10.1016/j.eja.2019.01.001.

Posters

Proposal of a method to penalize STICS outputs by considering bio-aggressor effects, within a long-term diversified cropping system simulation framework

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Keyword: diversification, cropping system, long term, bio-agressor

Introduction

The development of cropping systems based on biodiversity would make it possible to satisfy human food needs while reducing the environmental impacts of agriculture and strengthening the resilience of systems in the face of climate change (Carof et al., 2022). Crop diversification is an effective way of increasing biodiversity, both planned biodiversity (e.g., the crops chosen by the farmer) and associated biodiversity (e.g., the soil micro-organisms favoured by a given crop and its management).

One of the difficulties encountered when designing such systems is assessing the ecosystem services they provide over the long term, in the context of climate change. Dynamic models such as STICS go some way towards resolving this difficulty.

However, in order to remain relatively simple, to avoid the multiplication of uncertainties or to avoid over-adjustment, these models do not yet integrate certain effects that are essential in the description of cropping systems and in the evaluation of ecosystem services provided. In this sense, the idea of this work is to propose and test a simple method for adjusting the outputs of the STICS model to the effect of bio-aggressors on the cropping system which, at present, does not appear in the model.

Material and method

In this study, three-time steps are considered: the medium term, 10 years (from the start of a diversified rotation); the medium horizon, a period of 30 years (same three successive rotations); the long term, 50 years (same five successive rotations).

The STICS model (V10.0.0) was chosen because it has already been successfully used to model long-term cropping systems (Yin et al., 2020). The aim of STICS is to simulate the consequences of implementing diversified cropping systems at the different time steps described above and according to different climatic scenarios. Climatic data are derived from (i) SAFRAN models for current climatic data from 1973 to 2023, and (ii) DRIAS projection data for the period 2023-2073.

The cropping systems modelled were co-designed during participatory workshops with local experts (farmers, technicians and researchers), in order to obtain highly diversified systems (at least 6 different crops, over 6 years) that were also adapted to local pedoclimatic constraints (in this case, Brittany). This co-design phase focused on the choice of crops (and their succession), for their contribution to the provision of 10 different ecosystem services (see details in Appendix), based on their functional traits.

Results

Building on the study of Meunier et al. (2022), a method for quantifying the impacts of bio-aggressors (weeds, pathogens, pests) on the growth and development of cultivated plants has been set up: it is based on considering expert opinions on biomass losses caused by bio-aggressors. More precisely, the aim is to combine a mechanistic modelling method (hard model) with a decision-support approach based on expert opinions (soft model). The outputs of the hard model are thus penalized by a bio-aggressor factor, providing a more realistic representation of the performances of the cropping system simulated with STICS.

Following Meunier et al. (2022), the originality of the method consists in directly penalizing the STICS inputs by creating original "plant" files, representative of plants affected by bio-aggressors, using expert opinions. Compared with coupling STICS to existing mechanistic models, this method offers greater flexibility in considering a range of different bio-aggressors. The resulting meta-model, named STICSpest, is used to obtain variables of interest under the "bio-aggressor" constraint.

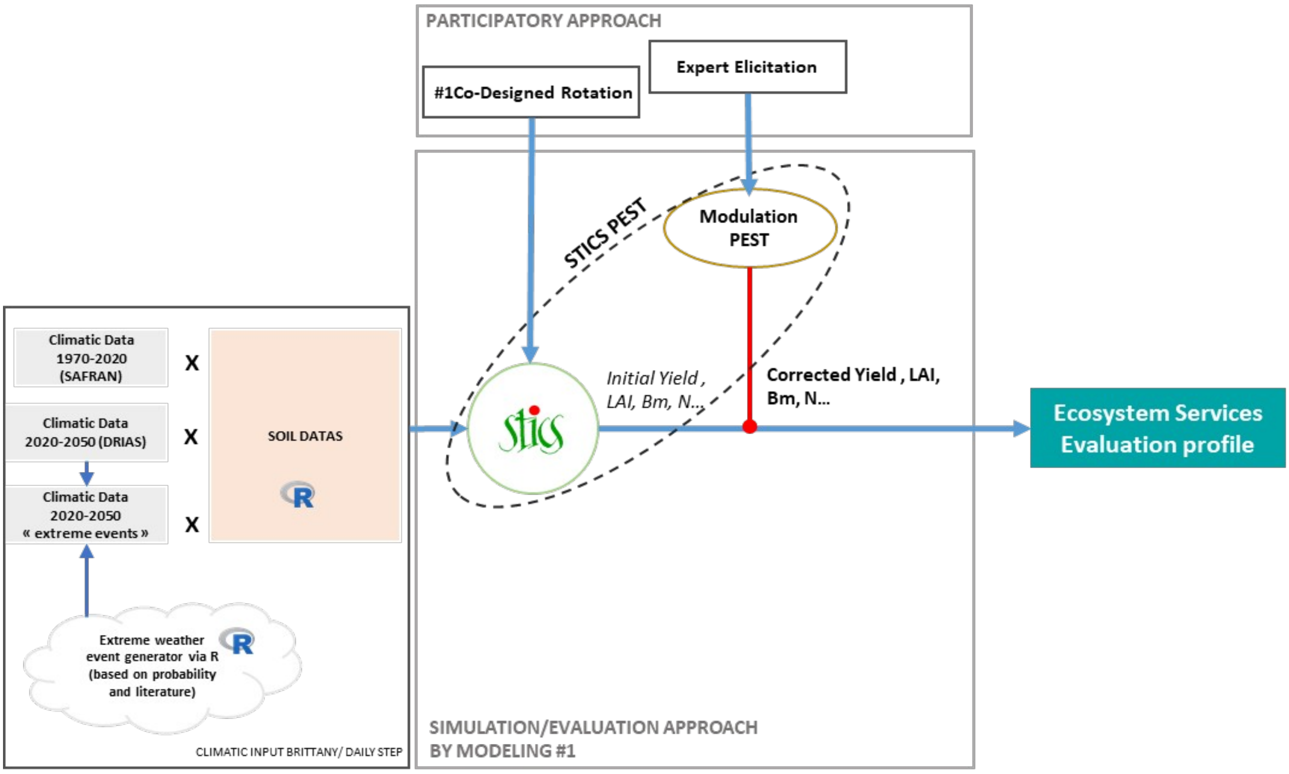

Figure 1 : STICS$_{pest}$ conceptual scheme

Conclusion

The modelling data obtained from STICSpest and the phosphorus balance sheet will then be used in a second co-design workshop to refine the cropping systems tested, focusing in particular on the choice of technical itinerary. The redesigned cropping systems will then be modelled on the same scheme, and re-evaluated. In addition to the method presented here, the end result will be to generate knowledge on the sustainability and resilience of diversified systems over the long term, which can be used as levers for action by Breton agricultural players in their agro-ecological transition.

References

Carof, M., Godinot, O., Le Cadre, E., 2022. Biodiversity-based cropping systems: A long-term perspective is necessary. Sci Total Environ 838, 156022.

Meunier, C., Alletto, L., Bedoussac, L., Bergez, J.-E., Casadebaig, P., Constantin, J., Gaudio, N.,
Mahmoud, R., Aubertot, J.-N., Celette, F., Guinet, M., Jeuffroy, M.-H., Robin, M.-H., Médiène, S., Fontaine, L., Nicolardot, B., Pelzer, E., Souchère, V., Voisin, A.-S., Rosiès, B., Casagrande, M., Martin, G., 2022. A modelling chain combining soft and hard models to assess a bundle of ecosystem services provided by a diversity of cereal-legume intercrops. European Journal of Agronomy 132.

Yin, X., Beaudoin, N., Ferchaud, F., Mary, B., Strullu, L., Chlébowski, F., Clivot, H., Herre, C., Duval, J., Louarn, G., 2020. Long-term modelling of soil N mineralization and N fate using STICS in a 34-year crop rotation experiment. Geoderma 357, 113956.

Appendix: List of ecosystem services studied and agroecosystem processes involved

TYPE OF SERVICES	FUNCTIONS OF THE AGROECOSYSTEM INVOLVED	SERVICES PROVIDED
Supplying	**Productivity of cultivated plants (yield, biomass)**	Production of edible commodities with sufficient quantity and good nutritional quality to meet the food needs of your island.
Regulation & Maintenance	**Leaching of minerals**	Mitigation of leaching of essential minerals for the growth of cultivated plants (primarily nitrogen and phosphorus)
Regulation & Maintenance	**Decomposition, fixation, mineralization**	Provision of essential CNP elements for plant growth
Regulation & Maintenance	**Pathogen regulation**	Control of fungal, bacterial, and viral diseases affecting cultivated species
Regulation & Maintenance	**Predation regulation**	Control of crop pests
Regulation & Maintenance	**Plant-plant competition**	Limitation/regulation of weed growth
Regulation & Maintenance	**Transpiration, evapotranspiration, infiltration, runoff**	Storage and release of water necessary for plant development
Regulation & Maintenance	**Denitrification and direct emission**	Reduction of greenhouse gas emissions by the system
Regulation & Maintenance	**Plant pollination**	Species in rotation provide additional resources for pollinators, ensuring continuous plant pollination.

PySTICS, a Python open-source implementation of STICS

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Keywords : agrivoltaics, python, open-source

Abstract

The STICS model is a popular crop model coded in Fortran. Simulations can be performed through a Java software, but this limits its adoption outside of academia. Python is now the most popular scientific programming language in the industry, and its adoption in academia is rapidly increasing.

A Python implementation of STICS, PySTICS, would benefit from several advantages. First, it would be easier to adopt by the community, especially for integration with complementary modeling systems. Second, Python's modular framework would enable easy development of new modules to consider domain-specific formalisms. Third, a Python library with degraded mode options would allow users to select only relevant modules and simplify the model when a full parametrization cannot be achieved.

Based on our interest in agrivoltaics research, we are currently developing PySTICS, with a focus on a degraded version with modules directly related to light interception and its influence on phenology and biomass production. We are progressively implementing other modules to get closer to the full version of STICS. Our approach and Python's modular framework will make it easy to implement more modules to consider agrivoltaics-specific formalisms.

PySTICS will be hosted on GitHub, a collaborative versioning tool, to facilitate contributions to the model and ensure versions traceability. GitHub's renown will also improve STICS visibility and make its adoption easier. We will present an open-source version of the current code, with a demonstration to users on how to simulate and export results.

References

De Wit, A., Boogaard, H., Fumagalli, D., Janssen, S., Knapen, R., van Kraalingen, D., ... & van Diepen, K. (2019). 25 years of the WOFOST cropping systems model. Agricultural systems, 168, 154-167. doi : https://doi.org/10.1016/j.agsy.2018.06.018

Développement d'un module de compétition pour l'eau entre cultures et adventices dans le modèle FLORSYS, couplé au modèle STICS simulant la quantité d'eau disponible dans le sol

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Mots clés : couplage de modèles, état hydrique du sol, modèle plurispécifique, modèle individu-centré, compétition, eau

Keywords: model coupling, soil water status, multispecies model, 3D individual-based model, competition, water

Contexte

FLORSYS (« FLOR » pour flore adventice, « SYS » pour système de culture) est un modèle mécaniste qui simule la dynamique pluriannuelle des adventices et le rendement des cultures en grandes cultures (Colbach et al., 2021). 3D et individu-centré, il reproduit au pas de temps journalier le développement et la croissance de chaque plante adventice ou cultivée dans la parcelle (exemple : photosynthèse, biomasse aérienne et racinaire totale…). Constitué de nombreux modules en interaction (qui représentent les phénomènes biophysiques, après mise en équations et paramétrage), le modèle est capable de donner chaque jour l'état général de la parcelle, qui peut être visualisé en 3D (Figure 1).

FLORSYS (Figure 1) prend en entrée (1) le stock semencier adventice initial (généralement estimé à partir de statistiques régionales), (2) les variables pédoclimatiques journalières (généralement jeux de données Météo France passés ou projections climatiques) et (3) les caractéristiques du système de culture, et produit plusieurs sorties. D'une part, le modèle peut renvoyer, sur tout ou partie de la durée de simulation, la dynamique journalière de différentes variables à l'échelle de la parcelle (biomasse végétale / m² ; nombre de plantes / m²…). D'autre part, FLORSYS fournit un tableau de scores par indicateur traduisant l'impact de la flore adventice sur la production des cultures (pertes de rendement, salissement du champ, …) et la biodiversité (offre trophique pour les abeilles…) (Mézière et al., 2015). Cet outil est régulièrement utilisé dans le cadre d'évaluations de systèmes de culture existants ou d'ateliers de (re)conception de systèmes résilients, selon les objectifs et contraintes des agriculteurs (exemples dans Colbach et al., 2021).

Le modèle simule déjà les mécanismes de compétition pour la lumière et pour l'azote (Munier-Jolain et al., 2013 ; Moreau et al., 2021), et un travail est cours pour intégrer la compétition pour l'eau (Cournault, 2023). FLORSYS sera alors le premier modèle mécaniste de dynamique de la flore adventice à représenter la compétition pour ces trois ressources majeures. Dans le modèle, la compétition pour les ressources est simulée à l'échelle de voxels 3D, qui constituent l'architecture de base (Figure 1).

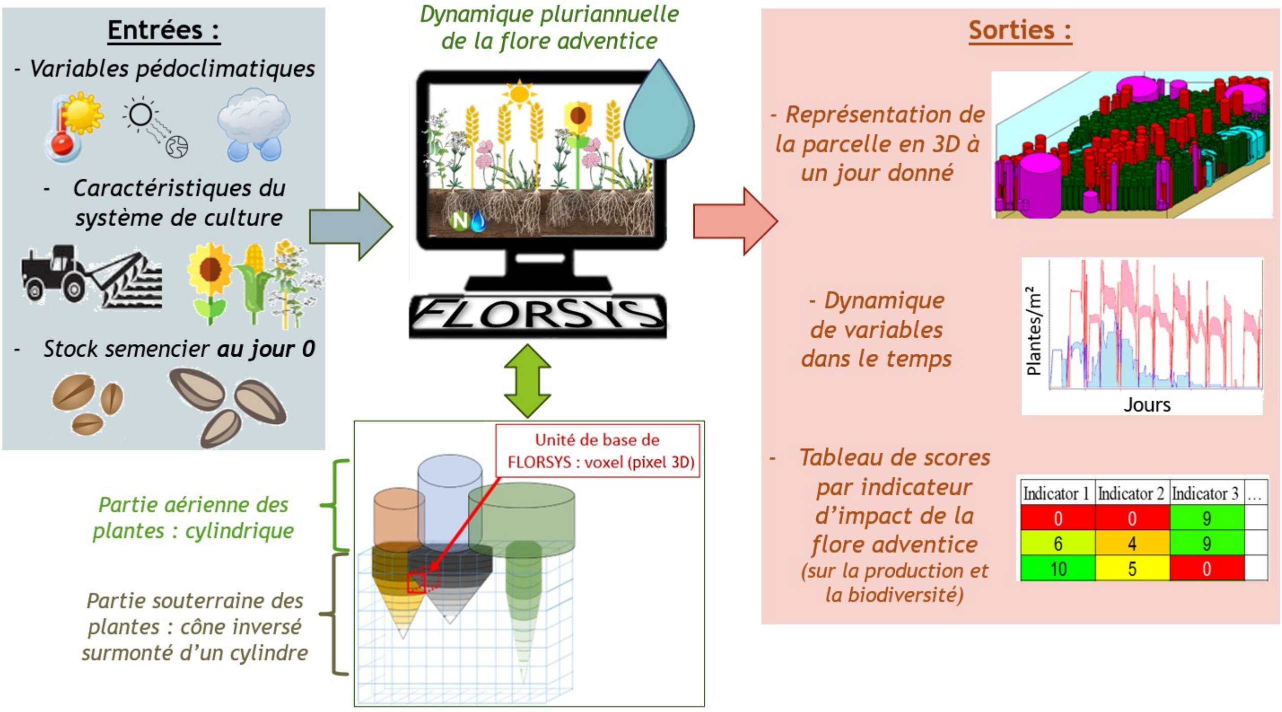

Figure 1 : Fonctionnement de FLORSYS (Colbach et al., 2021). Les plantes sont représentées de manière simplifiée dans le modèle et l'échelle de calcul de base dans FLORSYS est le voxel (3D). Les phénomènes de compétition pour les ressources sont donc étudiés à cette échelle.

Afin de simuler la compétition pour l'eau, trois processus sont en cours d'intégration dans FLORSYS :

- La demande en eau des plantes,

- L'offre en eau pour les plantes qui dépend de (1) la quantité d'eau disponible dans le sol (fonction de la météo, des caractéristiques du sol et de la présence de plante voisines), (2) la prospection racinaire et (3) la capacité de prélèvement des plantes,

- La réponse des plantes (morphologie et photosynthèse) à une limitation en eau.

Ce nouveau module considère que la compétition pour l'eau se produit entre plantes quand la quantité d'eau disponible dans un voxel de sol est insuffisante pour satisfaire les besoins en eau de toutes les plantes qui ont des racines dans ce voxel. La quantité d'eau disponible dans le sol (à pas de temps journalier et sur différentes couches de sol) est une variable-clef de ce module. Nous avons choisi de la prédire par un couplage avec le module sol de STICS. Ce couplage est présenté ici.

Objectif et démarche

Après le couplage STICS-FLORSYS dans le cadre de la compétition pour l'azote, un couplage est en cours pour la compétition pour l'eau. La difficulté réside dans la spatialisation différente du sol dans les deux modèles (Figure 2), avec STICS décrivant le sol en 1D, avec des horizons d'épaisseur d'1 cm, et FLORSYS discrétisant le sol en 3D avec des voxels de z cm (avec z choisi par l'utilisateur). Le principe de couplage est le suivant :

- À chaque début de journée, STICS donne à FLORSYS, pour chaque horizon de sol d'un cm, la concentration en eau disponible pour les plantes (g eau / g sol par cm, calculée depuis HUR-HUMIN). Afin de transférer cette donnée à FLORSYS, une transformation est effectuée : pour chaque couche de voxels 3D FLORSYS, l'humidité de chacun des voxels(g eau / voxel) de la couche est calculée à partir de la concentration moyenne (g eau / g sol par cm) des z horizons STICS correspondants, de la densité apparente du sol (g sol / cm² sol) et du volume d'un voxel (cm³)

- Au cours de la journée, chaque plante prélève une quantité d'eau (g / plante) dans les voxels du sol parcourus par ses racines.

- En fin de journée, la quantité d'eau prélevée par l'ensemble des plantes (prédite par FLORSYS) est sommée sur l'ensemble des voxels d'une couche donnée, puis réparties sur les z horizons STICS de la couche, au prorata de leur concentration initiale en eau. FLORSYS retourne alors à STICS cette eau prélevée (mm eau / cm sol par jour) qui retirera cette valeur (correspondant à la variable STICS EPZ) à l'eau du sol (HUR).

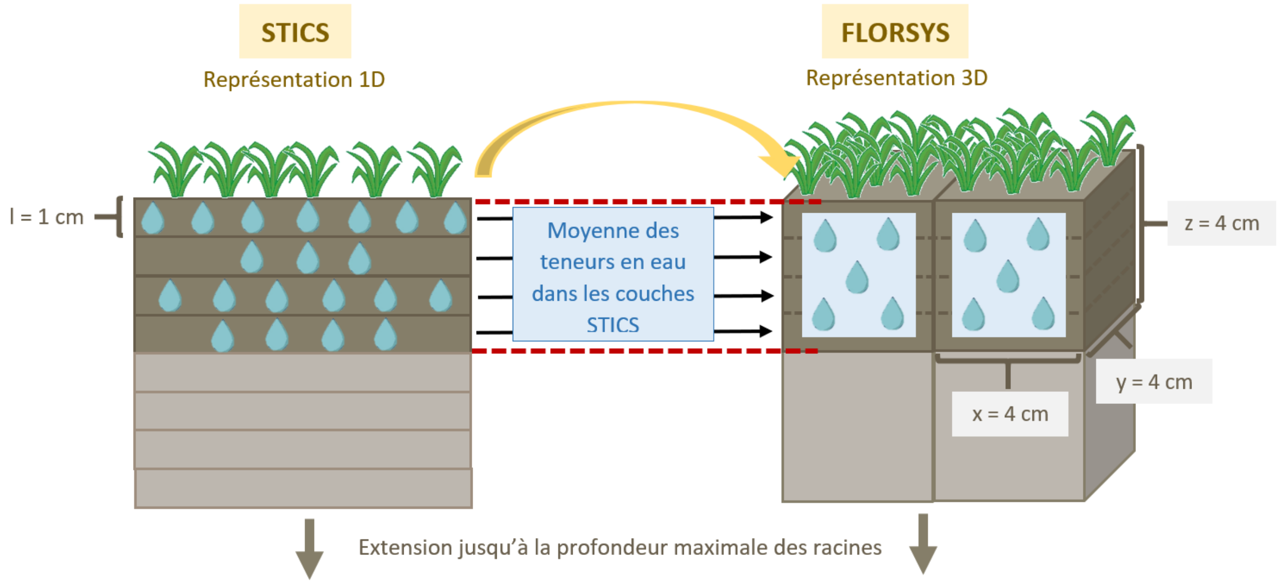

Figure 2 : Répartition de l'eau des couches STICS dans les voxels FLORSYS. Exemple pour des voxels de dimension 4 x 4 x 4 cm. Le nombre de gouttes d'eau correspond à la concentration relative en eau de chaque couche STICS. Tous les voxels FLORSYS d'une même couche z contiennent la même teneur en eau.

Ce couplage est actuellement en cours de codage, de même que les phénomènes biophysiques qui déterminent le prélèvement en eau par les plantes et les conséquences du stress hydrique sur la photosynthèse et la morphologie végétale. Une fois le module terminé, des simulations seront réalisées avec la nouvelle version de FLORSYS, afin d'en étudier la robustesse et la crédibilité. La version améliorée du modèle sera par la suite mobilisée dans le cadre d'une thèse visant à étudier les impacts régionalisés du changement climatique sur la nuisibilité adventice en grandes cultures.

Remerciements

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Références bibliographiques

Colbach N., Colas F., Cordeau S., Maillot T., Queyrel W., Villerd J., et Moreau D. 2021. The FLORSYS crop-weed canopy model, a tool to investigate and promote agroecological weed management. Field Crops Research, 261, p. 108006. DOI : 10.1016/j.fcr.2020.108006

Cournault Q. 2023. Intégration de la compétition pour l'eau entre différentes cultures d'intérêt et adventices dans un modèle mécaniste d'évaluation de nuisibilité de la flore adventice au champ : FLORSYS. UMR 1347 Agroécologie, INRAE Bourgogne-Franche-Comté ; Stage de fin d'études d'ingénieur, Institut Agro Dijon.

Mézière D., Petit S., Granger S., Biju-Duval L., et Colbach N. 2015. Developing a set of simulation-based indicators to assess harmfulness and contribution to biodiversity of weed communities in cropping systems. Ecological Indicators, 48, p. 157-170. DOI : 10.1016/j.ecolind.2014.07.028

Moreau D., Pointurier O., Perthame L., Beaudoin N., Villerd J., et Colbach N. 2021. Integrating plant-plant competition for nitrogen into a 3D individual-based model simulating the effects of cropping systems on weed dynamics. Field Crops Research, 268 (108166), p. 21. DOI : 10.1016/j.fcr.2021.108166

Munier-Jolain N.M., Guyot S.H.M., et Colbach N. 2013. A 3D model for light interception in heterogeneous crop:weed canopies: Model structure and evaluation. Ecological Modelling, 250, p. 101-110. DOI : 10.1016/j.ecolmodel.2012.10.023

Prédiction de la croissance et de la valeur nutritive de la luzerne dans l'Est du Canada avec le modèle STICS

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Mots clés : Luzerne, STICS V10, calibration, croissance, valeur nutritive.

Introduction

La luzerne est l'une des espèces fourragères pérennes les plus cultivées au monde. Elle est particulièrement appréciée pour sa concentration élevée en fibres digestibles et en protéines. Au Canada, de nombreux travaux ont été faits depuis plusieurs années pour sélectionner des plants plus tolérants au froid, avec une meilleure dormance automnale, tout en étant plus digestibles (Claessens et al., 2022). Avec la nouvelle version 10 de STICS qui permet de simuler plus précisément la croissance et l'accumulation d'azote des plantes pérennes (Strullu et al., 2020), des travaux ont été entrepris pour calibrer deux cultivars de luzerne utilisés au Canada, Oneida VR et Calypso, pour ensuite utiliser les résultats de simulations de biomasse pour prédire sa valeur nutritive.

Matériel et méthodes

Au total, 24 jeux de données provenant de cinq sites situés dans l'Est du Canada ont été utilisés pour la calibration et l'évaluation de la performance du modèle à simuler la croissance de ces deux cultivars (Tableau 1). Le modèle a été calibré en utilisant soit des valeurs de paramétrage provenant de la littérature, soit un processus itératif d'essais et d'erreurs et/ou en minimisant la différence entre les sorties du modèle et les valeurs observées de biomasse aérienne et d'indice de surface foliaire (LAI) à l'aide du package R *CroptimizR* (Buis et al., 2023). Lors du processus de calibration, deux paramètres plante et six paramètres variétaux et ont été modifiés pour l'un ou l'autre des cultivars. Les valeurs des autres paramètres intervenant dans la simulation de la croissance de la luzerne et déterminées par Strullu et al. (2020) ont été conservées.

Tableau 1. Description des jeux de données pour la calibration et l'évaluation du modèle.

Sites[1]	Années	Semis	Repousses	Cultivars	Nombre d'observations		
					Biomasse	LAI	VN[2]
Calibration							
Fredericton (NB)	1992-1993	Oui	Non	OneidaVR	22	21	14
Mtl, Lévis, Lac-St-Jean (QC)	2015-2016	Non	Oui	Calypso	46	-	46
Évaluation							
Fredericton (NB)	1992-1993	Oui	Non	OneidaVR	44	42	28
Mtl, Québec, Lévis, Lac-St-Jean (QC)	2015-2016	Non	Oui	Calypso	90	-	90

[1] Mtl : Ville de Montréal, NB : Province du Nouveau-Brunswick, QC : Province de Québec. [2] VN : Valeur nutritive. Comprend les fibres au détergent neutre (NDF), la digestibilité des fibres NDF (NDFd), et la digestibilité in-vitro de la matière sèche (IVTD).

Résultats

Les deux paramètres plante modifiés lors de la calibration sont la fraction de remobilisation des réserves de carbone (*remobres*) qui a été augmentée, et la fixation symbiotique maximale (*fixmaxveg*) selon la valeur utilisée dans Autret et al. (2020) puisqu'il y avait un important stress azoté simulé en utilisant la valeur initiale. Les paramètres cultivars modifiés sont le taux maximal d'augmentation quotidienne brut de LAI (*dlaimaxbrut)*, la température optimale de croissance de la plante (*teopt)*, le cumul des unités de développement (en degrés jour) entre l'émergence et la fin de la phase juvénile (*stlevamf)* et entre la fin de la phase juvénile et la fin de la croissance des feuilles (*stamflax)*, un paramètre de compétition inter-plante (*adens)* et le taux d'élongation du front racinaire (*croirac)*.

De bons résultats ont été obtenus sur les jeux de données utilisés pour la calibration, avec une NRMSE (*normalized root mean square error*) de 21.5% et 23.8% pour la croissance de la biomasse aérienne pour les cultivars Oneida VR et Calypso, respectivement. Le LAI a aussi été convenablement prédit avec une NRMSE de 26.7% et une efficience (EF) de 0.76. L'évaluation du nouveau paramétrage a donné de bons résultats pour Oneida VR avec une NRMSE de 20.0% et 26.4% et une EF de 0.87 et 0.76 pour les prédictions de biomasse aérienne et le LAI, respectivement. Pour Calypso, avec une NRMSE de 28.0% et une EF de 0.63, les valeurs de biomasse aérienne les plus élevées, principalement celles en fin de repousse, étaient sous-estimées. Cette sous-estimation à la récolte apparaît plus importante en première coupe (NRMSE de 29%) qu'en deuxième coupe (NRMSE de 19%).

Suite et perspectives

Suite à la calibration de ces cultivars, la croissance prédite par STICS sera utilisée pour simuler la valeur nutritive de la luzerne, plus spécifiquement les fibres insolubles au détergent neutre (NDF), la digestibilité in-vitro des fibres NDF (NDFd) et la digestibilité in-vitro de la matière sèche (IVTD), à l'aide des équations du modèle CATIMO (Bonesmo et Bélanger, 2002), qui ont déjà été utilisées dans STICS pour simuler la valeur nutritive de la fléole des prés (Jégo et al., 2013). Les paramètres de ces équations seront optimisés, à l'aide des données de valeurs nutritives mesurées aux mêmes sites (Tableau 1).

Références

Autret, B., Mary, B., Strullu, L., Chlebowski, F., Mäder, P., Mayer, J., Olesen, J. E., Beaudoin, N. 2020. Long-term modelling of crop yield, nitrogen losses and GHG balance in organic cropping systems. Science of the Total Environment., 710, 134597. https://doi.org/10.1016/j.scitotenv.2019.134597

Bonesmo, H., Bélanger, G. 2002. Timothy yield and nutritive value by the CATIMO model: II Digestibility and fiber. Agronomy Journal, 94. https://doi.org/10.2134/agronj2002.3450

Buis, S., Lecharpentier, P., Vezy, R., Giner, M., 2023. CroptimizR: A Package to Estimate Parameters of Crop Models (Version 0.5.1).

Claessens, A., Bertrand, A., Thériault, M., Baron, V., Lajeunesse, J., Schellenberg, M., Rocher, S. 2022. Agronomical evaluation of low dormancy alfalfa populations selected by an indoor screening method. Crop Science. https://doi.org/10.1002/csc2.20779

Jégo, G., Bélanger, G., Tremblay, G.F., Jing, Q., Baron, V.S. 2013. Calibration and performance evaluation of the STICS crop model for simulating timothy growth and nutritive value. Field Crops Research. 151, 65-77. https://doi.org/10.1016/j.fcr.2013.07.003

Strullu, L., Beaudoin, N. , Thiébeau, P. , Julier, B., Mary, B., Ruget, F., Ripoche, D., Rakotovololona, L. Louarn, G. 2020. Simulation using the Stics model of C&N dynamics in alfalfa from sowing to crop destruction. European Journal of Agronomy 112. https://doi.org/10.1016/j.eja.2019.125948

Évaluation multicritère des performances agronomiques et environnementales de systèmes agricoles en Occitanie

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Mots-clés : indicateurs, acteurs agricoles, agroécologie, gaz à effet de serre (CO2, N2O), séquestration de carbone, modélisation, observatoire

Résumé : Pour répondre aux grands défis que doit relever le monde agricole qui sont la sécurité alimentaire, le changement climatique et la perte de biodiversité de nos campagnes, il va être indispensable d'adapter l'agriculture en utilisant des leviers multiples à différentes échelles spatiales et temporelles, adapter les grandes cultures par l'éco-efficience et accélérer la transition agroécologique (Resinter 2023). Dans ce contexte, il est important d'approfondir la connaissance des facteurs de contrôles des flux et bilans de carbone, azote et hydrique sur les agroécosystèmes, les confronter à des objectifs agronomiques et économiques en proposant une étude diagnostique et pronostique multicritères (Derrien et al. 2023, Prost et al. 2023, Sethuraman et al. 2021). Dans ce projet, il s'agit de modéliser le fonctionnement d'agrosystèmes du Sud-Ouest de la France au moyen du modèle STICS (Simulateur mulTIdisciplinaire pour les Cultures Standards ; Brisson et al. 1998), et d'analyser les résultats selon les points de vue hydrique, agronomique (quantités d'azotes et d'eau utilisées, séquestration de carbone, rendement), voire socio-économique (marges, coût de production), impact climatique par l'estimation de leurs bilans de gaz à effet de serre (CO_2 et N_2O principalement), selon différents niveaux d'organisation, la parcelle, l'exploitation et le bassin versant agricole. Cet exercice de simulation sera réalisé d'abord rétrospectivement, puis prospectivement sur la base de différents scenarii climatiques et de pratiques agroécologiques concertées avec les agriculteurs. Ces travaux s'appuieront sur un riche et plutôt rare jeu de données issues d'observations continues, long termes (18 années) et pluridisciplinaires, assurées dans le cadre de l'Observatoire Spatial Régional Sud-Ouest et des grandes infrastructures de recherches nationales (ZA PYGAR, IR OZCAR) et internationales (ERIC ICOS). Sur le plan scientifique, ce projet inclut un volet méthodologique, avec l'évaluation du modèle STICS dans un contexte régional avant-gardiste pour l'étude des effets du changement climatique (canicule et sècheresse annuelle), et un volet thématique. Les objectifs thématiques du projet sont notamment d'estimer (1) le potentiel de stockage du carbone organique dans les sols de systèmes de culture actuels typiques de l'Occitanie dédiés à la production céréalière ou laitière, (2) le potentiel d'augmentation du carbone organique des sols (COS) avec des scénarios impliquant des pratiques agricoles supposées augmenter le stockage de l'eau et du COS (Chaplot et Smith, 2023 ; Derrien et al 2023), (3) les bilan GES (N_2O, CO_2) pluriannuels de ces systèmes de culture, (4) de confronter dans cette analyse multicritères, les indicateurs agro-environnementaux et socio-économiques (rendement et revenus) puis (5) d'analyser l'effet des pratiques agricoles hétérogènes et de la variabilité météorologiques sur ces indicateurs. Au travers de cette communication nous présentons le jeux de données, la démarche suivie de mise en place des simulations ainsi que les premiers résultats du volet méthodologique du projet portant sur la calibration/validation de STICS, prévue pour être menée sur 2 parcelles agricoles ICOS à gestion contrastée. L'une appartient à une ferme de production céréalière, suit une rotation blé-tournesol-blé-colza et reçoit une fertilisation minérale. Seul le grain est exporté, les pailles sont restituées au sol. Un labour est pratiqué tous les 10 ans. L'autre appartient à une production laitière, suit une rotation blé-maïs ensilé irrigué et reçoit une fertilisation minérale et organique (lisier, fumier). Toute la biomasse produite est exportée pour nourrir les vaches et pailler l'étable. Les variables d'intérêt simulées avec STICS et qui sont confrontées aux mesures terrains sont la teneur en

azote minéral du sol, son contenu en eau, sa température, les flux de N_2O, d'Evapotranspiration et de CO_2 (Delandmeter et al., 2023), la production de biomasse, l'indice de surface verte et le rendement. Les flux de N2O n'étant mesuré qu'à compter de 2012 (Tallec et al., 2022), les simulations rétrospectives avec STICS permettront également d'estimer cette même variable sur la période 2005-2011 en vue d'obtenir des bilans de GES annuels complets en l'absence de mesures. De plus, STICS permet d'accéder à des variables du sol explicatives non régulièrement mesurées qui permettront de mieux comprendre les dynamiques observées en surface. Une fois cette étape franchie, le modèle sera appliqué sur des parcelles d'exploitations agricoles de la région pour lesquelles nous possédons les informations relatives aux itinéraires techniques et rendement passés (une dizaine d'années) ainsi que la comptabilité agricole (menée avec des étudiants IUT/école d'ingénieurs du secteur agricole) et sur lesquelles nous souhaitons mener l'étude multicritères en générant et confrontant bilans azote, carbone, eau du sol et bilan agroéconomique (rendement, gain pour l'agriculteur). La finalité est de travailler avec les acteurs agricoles et de les informer objectivement, sur la base de résultats scientifiques, des différents aspects agro-environnementaux du fonctionnement de leur parcelle et de co-produire de nouvelles connaissances. L'ultime étape sera de proposer cette même analyse multicritère en réalisant des exercices de simulation prospective (une quinzaine d'années) selon différents scenarii d'évolution climatique et de changement de pratiques agricoles. Ces derniers scénarii seront recueillis avec la mise en place d'atelier de concertation/interview avec les acteurs agricoles au format living lab.

Références :

Brisson et al., 1998. STICS: a generic model for the simulation of crops and their water and nitrogen balances. I. Theory and parameterization applied to wheat and corn. Agronomie 18, 311–346. https://doi.org/10.1051/agro:19980501

Chaplot, V., Smith, P., 2023. Cover crops do not increase soil organic carbon stocks as much as has been claimed: what is the way forward? Glob.Change Biol.

Delandmeter et al., 2023. A comprehensive analysis of CO2 exchanges in agro-ecosystems based on a generic soil-crop model-derived methodology. Agric. For. Meteorol. 340, 109621. https://doi.org/10.1016/j.agrformet.2023.109621

Derrien et al., 2023. Current controversies on mechanisms controlling soil carbon storage: implications for interactions with practitioners and policy-makers. A review. Agron. Sustain. Dev. 43, 21. https://doi.org/10.1007/s13593-023-00876-x

Prost et al. 2023. Key research challenges to supporting farm transitions to agroecology in advanced economies. A review. Agron. Sustain. Dev. 43. https://doi.org/10.1007/s13593-022-00855-8

Resinter 2023, « Quels agriculteurs demain pour relever les défis de la sécurité alimentaire et du changement climatique ? » https://agriculture.gouv.fr/le-reseau-international-du-ministere-de-lagriculture-se-penche-sur-le-renouvellement-des-actifs

Sethuraman et al., 2021. Revamping Ecosystem Services through Agroecology-The Case of Cereals. Agriculture-Basel 11, 204. https://doi.org/10.3390/agriculture11030204

Tallec et al., 2022. Dynamics of nitrous oxide emissions from two cropping systems in southwestern France over 5 years: Cross impact analysis of heterogeneous agricultural practices and local climate variability. Agricultural and Forest Meteorology 323, 109093. https://doi.org/10.1016/j.agrformet.2022.109093

Simulation par une approche participative de l’effet de systèmes agroécologiques sur l’évolution de la matière organique des sols

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Keywords : modélisation, STICS, agroécologie, rotation de cultures, matière organique.

Introduction

L'agriculture est au premier rang des activités humaines directement affectées par le changement climatique. En conséquence, les agriculteurs sont de plus en plus encouragés à tenir compte de nombreux enjeux environnementaux dans leur processus décisionnel, dont les émissions de gaz à effet de serre et la séquestration du carbone. En Montérégie, comme dans la majeure partie des terres cultivées de l’Est du Canada, la matière organique (MO) du sol a globalement tendance à diminuer (https://agriculture.canada.ca/fr/production-agricole/sol-et-terre/indicateur-de-matiere-organique-du-sol) et certaines études associent cette tendance à la réduction de la proportion des terres cultivées en cultures fourragères pérennes au profit de cultures annuelles comme le maïs et le soja. Cependant, dans le cadre du projet du laboratoire vivant du Québec (LL-QC) d’Agriculture et Agroalimentaire Canada, il a été constaté que même des producteurs mettant en place plusieurs bonnes pratiques (ex. cultures de couverture, semis direct) pouvaient voir les teneurs en MO de leurs sols baisser. Afin d'améliorer notre compréhension de la dynamique actuelle de la MO du sol et d'évaluer les impacts agronomiques et environnementaux potentiels de différents systèmes de culture agroécologiques, des ateliers de modélisation participative incluant producteurs, conseillers agricoles et chercheurs ont été réalisés.

Matériel et méthodes

Plusieurs ateliers ont été organisés avec quatre agriculteurs du LL-QC dans un processus itératif pour (i) confirmer ou questionner avec un modèle sol-culture les tendances de la dynamique de la MO du sol observées grâce à des analyses répétées; (ii) concevoir et simuler l’effet de systèmes de culture agroécologiques alternatifs incluant de meilleures pratiques de gestion visant à améliorer le bilan carbone du sol; (iii) simuler l’effet des changements climatiques sur ces systèmes. Les systèmes de culture agroécologiques testés comprenaient des cultures annuelles de printemps en rotation (maïs, soja et céréales), des cultures d'automne, des cultures de couverture, des cultures fourragères pérennes, différentes intensités de travail du sol jusqu’au semis direct et des applications de fumier et de compost. Les simulations ont été réalisées avec le modèle STICS (Beaudoin et al., 2022) qui a été préalablement adapté au contexte pédoclimatique de l’Est du Canada (ex. Jégo et al., 2014; Crépeau et al., 2021; Saadi et al., 2022).

Résultats

Les simulations des systèmes de culture actuellement utilisés par les producteurs ont montré que le modèle pouvait reproduire correctement les tendances observées de MO du sol. Les simulations des systèmes agroécologiques alternatifs ont montré plusieurs effets positifs sur la teneur en MO du sol . Par exemple, sur un sol limoneux, en comparaison d’une rotation classique maïs-soja, l'ajout d’une culture d’automne (blé) et d’une culture intercalaire dans le maïs pourrait permettre d’augmenter la teneur en MO autour de 5.3 % au lieu de la voir descendre en dessous de 4.2 % avec la rotation de base (figure 1). Les simulations réalisées avec des scénarios de changement climatique ont montré que l'augmentation du taux de minéralisation due à une température plus élevée aurait probablement tendance à diminuer la capacité du sol à stocker de la MO.

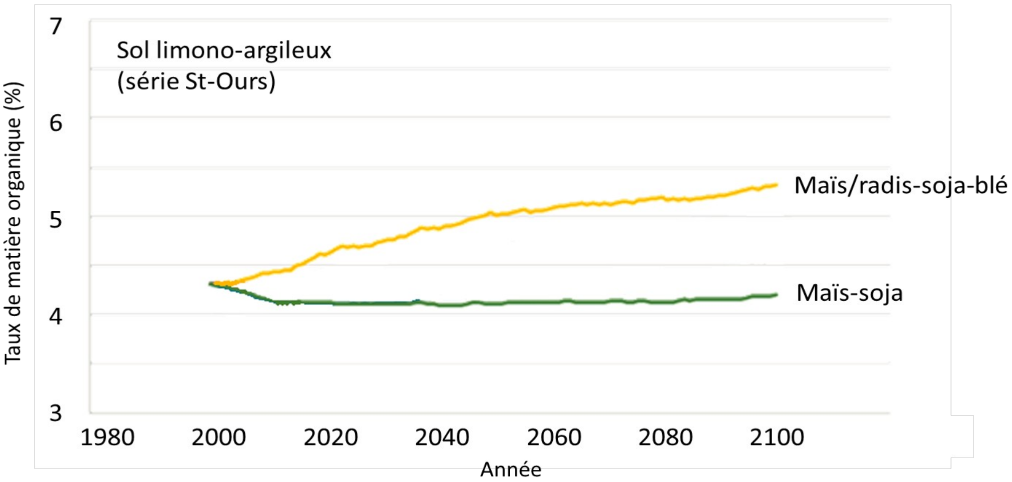

Figure 1. Évolution du taux de MO du sol pour la rotation de base maïs - soja et la rotation améliorée maïs avec radis en intercalaire – soja – blé d'automne.

Ce travail a fourni des résultats intéressants tant d'un point de vue scientifique qu'opérationnel en aidant à mieux comprendre les limites du modèle et les améliorations à y apporter comme par exemple la possibilité de simuler des associations culturales comportant plus que deux cultures. Il a aussi permis d'accompagner les agriculteurs dans les choix des systèmes de culture qui semblent avoir les meilleurs potentiels pour améliorer les teneurs en MO de leurs champs tout en maintenant des rendements élevés.

Références

Beaudoin N., et al. eds. 2022. STICS soil-crop model. Conceptual framework, equations and uses, Versailles, Éditions Quæ.
Crépeau, M., Jégo, G., Morissette, R., Pattey, E., Morrison, M.J., 2021. Predictions of soybean harvest index evolution and evapotranspiration using STICS crop model. Agron. J. 113, 3281-3298.
Jégo, G., Chantigny, M., Pattey, E., Bélanger, G., Rochette, P., Vanasse, A., Goyer, C., 2014. Improved snow-cover model for multi-annual simulations with the STICS crop model under cold, humid continental climates. Agric. For. Meteorol. 195-196, 38-51.
Saadi, S., Pattey, E., Jégo, G., Champagne, C., 2022. Prediction of rainfed corn evapotranspiration and soil moisture using the STICS crop model in eastern Canada. Field Crops Res. 287.

Comparing grazing intensities in crop-livestock systems with STICS

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Summary

Integrated crop-livestock systems (ICLS) are increasingly considered as key solutions to maintain high food production while minimizing agricultural impacts on the environment. But there is still little knowledge on the impact of adding a trophic level (i.e. herbivore animals) in cropping systems on their stability and resistance, as well as on soil fertility.

In that study, we established a methodology to simulate with the soil-crop model STICS the grazing process. We based on a 18-year ICLS field experiment in South Brazil (Rio Grande do Sul) consisting in soybean-pastures grazed by cattle beef, with contrasting grazing intensities (10, 20, 30 and 40cm grazing and one ungrazed treatment), to calibrate and validate the methodology. In that field experiment, each grazed paddock received three animals that remained throughout the whole experiment, plus a variable number of put-and-take animals that were regularly added or removed to maintain the targeted sward heights (Kunrath et al., 2020).

Based on Graux et al. (2020), we simulated frequent sward cuts (and associated cattle dung/urine inputs) to model the rate of return of the animal on a same plant and maintain the sward height as processed in the field experiment. The different plant parameters, for the soybean but also for the pasture composed of ryegrass and black oat, were adjusted from standard STICS parameters. Based on Da Souza et al. (2019), that measured steers individual DMI and fecal production, we also slightly adjusted the parameters of Graux et al. (2020) for computing cattle dung and urine, also considering that in our case, animals are steers and not milking cows. We also determined a ratio of conversion of forage into live weight gain, dependent on the grazing intensity.

Next we extrapolated the simulations to future climatic conditions at the same place (period 2040-2060, RCP8.5) to investigate the stability and resistance of these systems when facing climate change. They were mathematically computed from the characterization of climatic events as moderate or extreme, based on the SPEI drought index (Vicente-Serrano et al., 2010; Isbell et al., 2015).

It appeared that the ICLS systems have a greater total production (soybean, sward and meat) than the ungrazed treatment, with meat production increasing with grazing intensity. Soybean yields would globally decline with climate change but sward biomass would increase. Moderate grazing intensities seem ideal to adapt to and mitigate climate change, with greater resistance capacities and carbon sequestration.

References

Graux, A. I., Resmond, R., Casellas, E., Delaby, L., Faverdin, P., Le Bas, C., ... & Peyraud, J. L. (2020). High-resolution assessment of French grassland dry matter and nitrogen yields. *European Journal of Agronomy*, *112*, 125952. https://doi.org/10.1016/j.eja.2019.125952

Isbell, F., Craven, D., Connolly, J., Loreau, M., Schmid, B., Beierkuhnlein, C., ... & Eisenhauer, N. (2015). Biodiversity increases the resistance of ecosystem productivity to climate extremes. *Nature*, *526*(7574), 574-577. https://doi.org/10.1038/nature15374

Kunrath, T. R., de Albuquerque Nunes, P. A., de Souza Filho, W., Cadenazzi, M., Bremm, C., Martins, A. P., & de Faccio Carvalho, P. C. (2020). Sward height determines pasture production and animal performance in a long-term soybean-beef cattle integrated system. *Agricultural Systems*, *177*, 102716. https://doi.org/10.1016/j.agsy.2019.102716

Vicente-Serrano, S. M., Beguería, S., & López-Moreno, J. I. (2010). A multiscalar drought index sensitive to global warming: the standardized precipitation evapotranspiration index. *Journal of climate*, *23*(7), 1696-1718. https://doi.org/10.1175/2009JCLI2909.1

Calibration and validation of the STICS crop model to simulate the growth and development of Kernza, a promising perennial grain crop.

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Introduction

Annual crops production currently encounters several challenges regarding environmental impact in the global context of agroecological transition. Perennial crops are seen as one potential solution to address some of these challenges. Indeed, it could prevent issues such as fertilizing nutrients leaching or soil erosion generated when soils are left uncovered or ploughed annually. It also enhances carbon storage and biodiversity protection. Several selection programs are currently taking place to create perennial versions of annual cereals such as rice, barley, rye and wheat.

Regarding perenniality and grain production, one of the best foreseen candidates to produce perennial wheat is *Thinopyrum intermedium* ((Host) Barkworth & D.R. Dewey), commercialized under the name of Kernza®. Its recent selection history is turned towards the increase of thousand kernels weight and the ease of threshing. Additionally, Its original use as a forage crop makes it possible to consider a dual purpose of grain and fodder production during the same cropping year. This relatively new type of crop brings questions and challenges regarding management practices, integration into current cropping systems, impact on soils and agronomic potentials (Duchene et al., 2019). The use of crop models to simulate Kernza growth and development is therefore a relevant method to assess its potential coupled with spatial simulation.

Material and method

The 9.2 version of the STICS crop model was chosen to simulate Kernza growth and development due to its great proven capabilities to simulate a wide range of different crops. This will allow simulating Kernza inside crop rotations. Unfortunately, the model was not able to simulate the dual production of grain and forage of the plant at the same time. Two approaches were then used to simulate the plant. First considering the plant as a perennial forage crop that was cut for aerial biomass. The grain harvest was simulated using an harvest index applied on the final biomass harvested. The second approach considered the plant as an annual crop with a grain harvest but not forage harvest. In this second case, the perenniality of the crop was simulated using an external script taking output of a simulation as input for the next one.

The model was calibrated for each approach using field data from two Belgian experiments. One field was sown in 2017 and tested a gradient of nitrogen fertilization crossed with or without forage cut, the data was collected during four years. The other field was sown in 2019 and tested a combination of sowing dates and inter row spacing, the data was collected during two years.

Only certain variables were calibrated: the phenology, the leaf area index, the aerial dry matter, the grain yield, the nitrogen uptake and the root biomass.

Results

From the two approaches only the one considering the plant as an annual crop yield good results. The forage production in this approach is not taken into account but represents a really low amount of biomass.

Phenology, grain yield, aerial biomass and nitrogen uptake gave the best results with Nash–Sutcliffe modelling efficiency coefficient superior to 0.6 in calibration and validation. RMSE values were also good for these variables. Leaf area index calibration gave middle performances (coefficient of 0.32) when root biomass performed poorly (negative coefficient in calibration and validation).

Despite the overall good performances of the model in the simulation of Kernza, the second year of development was always underestimated in terms of yield, dry biomass and nitrogen uptake. This second development year corresponds to a yet unexplained peak production in reality.

After this promising first attempt to simulate Kernza, the calibration of the 10th version of the model on new data coming from France and Sweden will be done with the hope of improving root biomass simulation performances. After this, the model will be spacialized at the European level to assess the plant performances in future climate in a European context.

References

Olivier Duchene, Benjamin Dumont, Douglas J. Cattani, Laura Fagnant, Brandon Schlautman, Lee R. DeHaan, Spencer Barriball, Jacob M. Jungers, Valentin D. Picasso, Christophe David, Florian Celette,Process-based analysis of Thinopyrum intermedium phenological development highlights the importance of dual induction for reproductive growth and agronomic performance,Agricultural and Forest Meteorology,Volumes301–302,2021,108341, ISSN0168-1923, https://doi.org/10.1016/j.agrformet.2021.108341.

Évaluation multicritère des performances agronomiques et environnementales de systèmes agricoles en Occitanie

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Mots-clés : indicateurs, cultures, agroécologie, gaz à effet de serre (CO_2, N_2O), séquestration de carbone, cycles biogéochimiques, modélisation, observatoire

Résumé :

Approfondir la connaissance des facteurs de contrôle des flux et bilans de carbone, azote et hydrique dans les agroécosystèmes, les confronter à des objectifs agronomiques et économiques en proposant une étude diagnostique et pronostique multicritères est au cœur des problématiques scientifiques et sociétales actuelles. Dans ce projet, il s'agit de modéliser le fonctionnement d'agrosystèmes, selon les points de vue hydrique, agronomique (quantités d'azotes et d'eau utilisées, séquestration de carbone, rendement), voire socio-économique (marges, coût de production), impact climatique par l'estimation de leurs bilans de gaz à effet de serre (CO_2 et N_2O principalement), selon différents niveaux d'organisation, la parcelle, l'exploitation et le bassin versant agricole. Cet exercice de simulation sera réalisé d'abord rétrospectivement, puis prospectivement sur la base de différents scenarii climatiques et de pratiques agroécologiques concertées avec les agriculteurs. Les simulations rétrospectives s'appuieront sur un riche et précieux volume de données issues d'observations continues, long termes (18 années) et pluridisciplinaires, assurées dans le cadre de l'Observatoire Spatial Régional Sud-Ouest et des grandes infrastructures de recherches nationales (ZA PYGAR, IR OZCAR) et internationales (ERIC ICOS). Sur le plan scientifique, ce projet inclut un volet méthodologique, avec l'évaluation du modèle STICS dans un contexte régional avant-gardiste pour l'étude des effets du changement climatique (canicule et sècheresse annuelle), et un volet thématique incluant plusieurs objectifs. Les objectifs thématiques du projet sont notamment d'estimer (1) le potentiel de stockage du carbone organique dans les sols de systèmes de culture actuels typiques de l'Occitanie dédiés à la production céréalière ou laitière, (2) le potentiel d'augmentation du carbone organique des sols (COS) avec des scénarios impliquant des pratiques agricoles supposées augmenter le stockage de l'eau et du COS, (3) les bilans GES (N_2O, CO_2) pluriannuels de ces systèmes de culture, (4) de confronter dans cette analyse multicritères, les indicateurs agro-environnementaux et socio-économiques puis (5) d'analyser l'effet des pratiques agricoles hétérogènes et de la variabilité météorologiques sur ces indicateurs. Au travers de cette communication nous présentons la démarche suivie ainsi que les premiers résultats du volet méthodologique du projet portant sur la calibration/validation de STICS, menée sur 2 parcelles agricoles ICOS à gestion contrastée (production céréalière *versus* production laitière) hautement instrumentées pour suivre en continu les flux de GES (N_2O, CO_2) et d'évapotranspiration, les variables météorologiques, les variables du sol (température, contenu en eau), et bénéficiant d'un suivi détaillé de la dynamique de la végétation (LAI, rendement) et des itinéraires techniques.

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