Conceptual basis, formalisations and parameterization of the STICS crop model, second edition

Nicolas Beaudoin, Dominique Ripoche, L. Strullu, Bruno Mary, Marie Launay, Joël Léonard, Patrice Lecharpentier, François Affholder, Patrick Bertuzzi, Samuel Buis, et al.

6-7 January 2020 – Montpellier

BOOK OF ABSTRACTS

XIIth Stics users seminar

https://www6.paca.inrae.fr/stics_eng/

Stics2020 is a side event of the iCROP symposium (https://www.icropm2020.org/)

XIIth Stics users seminar

Book of abstracts

Montpellier

6-7 January 2020

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EDITORIAL

The STICS team is happy to invite you to the 12th Stics users seminar.

This seminar is a side-session of the iCROPM symposium that gathers eminent crop modelers from all around the globe. The iCROPM will focus on advances in crop modelling in general, with a great diversity of models and views on crop modelling. This seminar will focus more specifically on the Stics model and on the scientists community familiar to, or interested in the way the model (i) conceptualizes and simulates cropping systems (ii) has evolves over the past years to account for an increasing range of cropping systems properties. It offers a unique opportunity to take advantage of the great diversity of the views and expertise of the scientists coming to Montpellier this week.

We chose to host the seminar at the Agropolis campus in Montpellier, at the French agricultural research and international cooperation organization CIRAD that works for the sustainable development of tropical and Mediterranean regions. It is not mere coincidence - it underlies our will to strengthen the ability of the Stics model to deal with issues at stake in tropical environments. This is also reflected in the program and the list of participants.

We truly hope you will enjoy this Stics2020 seminar, and that it will offer you the opportunity to connect and exchange with new people on your favorite topic as well as on other challenges you want to undertake for the future.

Thursday 6th February 2020

		Talk (min)	Discussion (min)	Speaker
8:00 - 9:00	Registration - CIRAD - Registration desk at Alliot Amphitheater			
		Chair:	E. Justes	
9:00 - 9:15	Welcome speeches	15		JP. Laclau (CIRAD) + P. Cellier (INRAE) + STICS team head
9:15 - 10:40	***Session 1: News from the last STICS workshop***			
	News and propects for the STICS team and network	20	5	E. Justes, D. Ripoche, M. Launay and S. Buis.
	The Red Book of STICS, towards version 2	2	-	N. Beaudoin
	The genesis of STICS v10 and new formalisms implemented in the next standard version	20	5	L. Strullu
	SticsRpacks: a set of packages for managing Stics from R	15	5	S. Buis S. & P. Lecharpentier
10:40 - 11: 00	*Coffee break*			
11:10 - 12:30	***Session 2: New formalisms and crop calibration for crop diagnosis***	Chair:	G. Falconnier	
	Development of a new formalism for the establishment of grain yield and protein for determinate growing plants in a dedicated research version of STICS	15	5	N. Beaudoin or B. Dumont
	Assessment of the impact of water stress on soybean yield in Canada using STICS	15	5	G. Jégo
	Comparison of sugarcane STICS model calibrations to simulate growth response to climate variability	15	5	M. Christina
	Use of the STICS model for simulating physiological and soil evolution in the Champagne vineyard under different scenarios	15	5	C. Demestihas
12:30 - 14:00	*Lunch break (Agropolis International - Vanille room)*			
14:00 - 15:30	***Session 3: Modelling intercropping with STICS***	Chair:	G. Louarn	
	How to model crop-weed competition for soil resources: Connecting the STICS soil submodel to the FLORSYS weed dynamics model	15	5	N. Colbach
	Improving the intercropping version of the STICS model for simulating inter-specific competition	15	5	R. Vezy
	Calibration and Evaluation of the STICS Intercrop Model for Two Cereal-Legume Mixtures	15	5	K. Paff

	Modelling the agronomic performance of millet-cowpea intercropping under the semi-arid environment of Senegal.	12	3	Y. Senghor
	Calibration of STICS soil-crop model for sorghum crop mixed with cowpea bean to evaluate the performance of this crop-system in sub-Saharan Africa	12	3	A. Traoré
15:30 - 16: 00	*Coffee break*			
16:00 - 17:30	***Session 4: Methods and new tools for modelling with STICS***	Chair:	F. Affholder	
	AgGlob: Workflow for simulation of agronomic models at a global scale	15	5	H. Raynal
	Preliminary coupling of STICS (v9.1) to PEcAn ecological informatics toolbox, and its comparison to BASGRA	15	5	I. Fer
	A global optimization tool for assimilation of leaf area index into STICS crop model	15	5	M. Mesbah
	STICS on SIWAA: A STICS Tool set deployed on the SIWAA Galaxy Web platform	12	3	P. Chabrier
	A new method for sensitivity analysis of models with dynamic and/or spatial outputs	12	3	S. Buis
17:30	**End of the 1st day**			
17:30 - 19: 00	***Free time and Transfer to Montpellier social dinner place with public transports***			
19:00 - 23 :00	Social dinner – Villa mont-riant - Montpellier - 6 boulevard vieussens			

Friday 7th February 2020

9:00 - 10:00	***Session 5: Environmental impact of cropping systems and soil C&N dynamics***	Chair:	I. Garcia de Cortazar	
	Verification and long-term simulations of STICS crop model to predict and analyze growing seasons N_2O fluxes of spring wheat in eastern Canada	15	5	E. Pattey
	Modelling decomposition and N_2O emissions of mulches varying in quantity and quality	15	5	B. Chaves
	Modelling short and long-term nitrogen and carbon budgets of agro-ecological cropping systems with a dedicated STICS research version	15	5	N. Beaudoin
10:00 - 10:50	***short talks (presentation of posters)***			
	STICS ability to simulate long-term soil organic matter dynamics in crop-grassland rotations	5	2	A.I. Graux (A. Cadero)
	Simulation of switchgrass biomass production in Eastern Canada with the STICS model	5	2	G. Jégo

	Modelling the impact of soil and climatic variability on sugarcane growth response to mineral and organic fertilisers	5	2	M. Chaput
	Impact of corn root growth parameters on soil moisture, evapotranspiration and crop growth in STICS model	5	2	E. Pattey (S. Saadi)
	Impacts of observed and projected climatic constraints on rainfed wheat yield under a typical Mediterranean condition	5	2	C. Yang
	Coupling Sentinel-2 images and STICS crop model to map soil hydraulic properties	5	2	K. Lammoglia
10:50 - 11:10	*Coffee break*			
11:10 - 12:30	***Session 6: Regional and large scale simulations using STICS***	Chair:	E. Pattey	
	Estimate demand for irrigation water and nitrogen fertilizers in Europe at different scales	15	5	PA Jayet
	Regional-scale coupled modelling of water pollution by nitrate from agricultural sources: the Seine-Normandy hydrosystem case study	15	5	N. Gallois
	Simulating innovative cropping systems aiming at producing biomass while reducing greenhouse gas emissions in the Hauts-de-France region	15	5	F. Ferchaud
	New crop fertilization strategies after introduction of anaerobic digesters in a territory and their consequences on carbon and nitrogen dynamics in soils: case study of the Versailles plain	15	5	C.Launay
12:20 - 14:00	*Lunch break (Agropolis International - Vanille room)*			
14:00 - 14:45	***Session 7: Scenario simulations using STICS***	Chair:	M. Launay	
	To maximize multiple ecosystem services without dis-service for water, the management of cover crops has to be climate and soil specific. A simulation approach using STICS model.	15	5	N. Meyer
	Simulating soil organic carbon dynamics in long-term bare fallow and arable experiments with STICS model	15	5	F. Ferchaud (H. Clivot)
	Participative approach with STICS for evaluation of nitrogen management scenarios in organic farming systems	5	2	N. Beaudoin
14:45 - 15:30	**Invited conference**: The “business” of developing and delivering a systems model – the APSIM experience	30	10	PJ Thorburn
15:30 - 16:00	**Concluding session**: Conclusion and General discussion on STICS team governance	15	20	STICS team head: E. Justes, D. Ripoche, M. Launay and S. Buis
16:00 - 16:30	*End of the Workshop with Coffee break*			

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Session 1: News from the last STICS workshop

Conceptual basis, formalisations and parameterization of the STICS crop model, second edition

Beaudoin N.[1], Ripoche D.[2], Strullu L.[3], Mary B.[1], Launay M.[2], Léonard J.[1], Lecharpentier P.[2], Affholder F.[4], Bertuzzi P.[2], Buis S.[5], Casellas E.[6], Constantin J.[7], Dumont B.[8], Durand J.L.[9], Garcia de Cortazar-Atauri I.[2], Ferchaud F.[1], Graux A.I.[10], Jego G.[11], Le Bas C.[12], Levavasseur F.[13], Louarn G.[9], Mollier A.[14], Ruget F.[4], Justes E.[5]

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Keywords : deterministic model, cropping system, agro-ecology, environment, use, coupling.

Introduction

Since its creation in 1996, STICS has evolved to respond to emerging issues (Beaudoin et al., 2019). The need to make the formalisms of the model accessible to a large community of users has led to the publication of the book "Conceptual basis, formalizations and parameterization of the STICS crop model", under the guidance of Nadine Brisson. The draft of the so-called red book was presented to the STICS seminar in Reims in 2007, then the book was published by Quae Eds in early 2009. This book was original because it is the only existing publication concerning an international crop model that describes exhaustively the model formalisms and a rare synthesis of disciplines in the service of knowledge and action on cultivated fields (Figure 1).

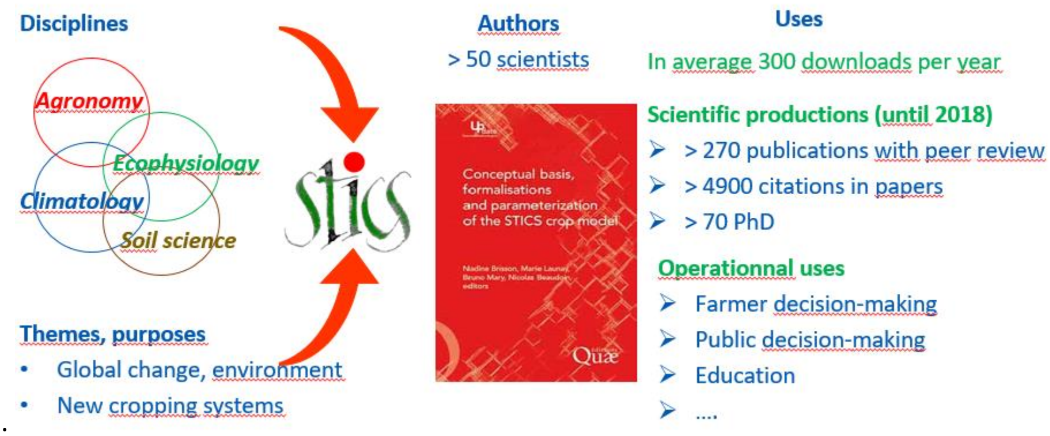

Figure 1: Diagram of the crossing of disciplines and scientific and technical productions allowed by STICS .

The limits of the 2009 edition lie in its paper format which does not allow a concomitant update to the evolution of the code. The challenge of the new project is to reinforce the dynamics of interaction between the evolution of the model, represented by the STICS Project Team (EPS), and the pluralistic community of users of STICS. The objective of the EPS is to propose a scalable version of the book giving it the status of key and up to date reference, and giving to the use of the model, a potentially unlimited life.

Material and methods

The design logic of the book builds on the achievements of the previous one: - description of all the formalisms of the STICS model, with the interaction processes between, crop, soil, climate and crop management at the plot scale; -detail of the construction hypotheses and equations of the model, illustrated by graphs; - display of operational information.

The new edition will bring novelties of substance and form. It will present the new processes introduced since 2008 (N_2O emission processes, snow module, nitrogen perennial reserve, root turn-over, specificities of grassland …). It will display intercropping processes over all the chapters, devote two chapters to helping user involvement and extending model capabilities for various applications (Table 1). Mathematical equations will be written in an academic way and can be directly tested via R Markdown to ensure reproducibility. A dematerialized edition will be available free of charge for each new version. Besides, there will be possible to print it on demand (with fees).

The project management is entrusted by the EPS to an editorial committee, which is composed of 6 members. On a technical level, the project has been submitted to QUAE Eds, who are interested in its dynamic and innovative character. The writing is organized in a modular way at the level of each chapter which is coordinated by 2 persons. It will rely on the 2009 writing and will seek new contributors, the list of which will be drawn at the chapter level. The writing is planned for the first semester 2020 for publication at the end of the year 2020.

	Chapter	**Novelties in the chapter content**	**page number**	
N°	Title		old	next
Preface	*backgrounds and new challenges for crop models*		2	2
1	Introduction	Java interface, tools for users	2	7
2	Overall description of the model system	C-N crop compartiments, priority between processus, intercropping	6	8
3	Development	Pluriannual forages	22	22
4	Shoot growth.	Perennial N reserve, LAI of pluriannual crops and forages, reserve allocation	26	28
5	Root growth	Daily root turn-over; root size, root length distribution, pluri-annual crops	8	10
6	Yield formation	C-N Harvest index dynamic versus remobilizations and water supply	12	12
7	Soil-crop management effects	Pluriannual or forage crop management, fertiliser calendar	16	16
8	Microclimate and energy balance	Interception by intercrops, snow module	26	28
9	Water Balance	Effect of mulch.	22	22
10	Carbon and Nitrogen transformations	Residusphere, SON mineralisation; organic supply; N & GHG balances	28	31
11	Transfers of heat, water and NO3		14	12
12	Long term simulation of cropping systems	Rotation with pluriannual crops; Prospectives with climatic scenarios	10	10
13	Ways of STICS use at several geographical scales	Typology of use, spatial distribution, ways of STICS coupling	0	10
14	Tools for a smart use of the standard version	New javastics options, metadata use	34	35
15	Methods of model capacity extension	Evaluation prediction tools; adaptation tof new crops; research versions	0	6
Annex	*References, parameters, index, publications, gaff, motto*	Lists of new parameters, publications and PhD thesis, gaff and motto	68	86
total			**296**	**345**

Table 1: List of planned chapters and novelties.

References

Beaudoin N., et al. (2019). Modélisation du fonctionnement des agro-écosystèmes: l'épopée STICS, in une agronomie pour le XXI siècle, Richard G., Stengel P., Lemaire G., Cellier P., Valceschini E cords, Quae Eds, pp 128-149.

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The genesis of STICS v10

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Mots clés : plantes pérennes, flux de C et N dans les systèmes de culture,

Keywords : perennial crops, C and N fluxes in cropping systems

Introduction

STICS model was initially developed to simulate crop yields, water and nitrogen fluxes in plants and soils. It was applied to annual crops and grasslands. Its main environmental goal was the protection of water resources. Recently, new challenges appeared concerning the carbon sequestration in agricultural soils, the emission of greenhouse gases and the production of renewable energy from biomass with dedicated perennial crops. This lead to new model developments allowing the simulation of new processes in diversified cropping systems including annual and perennial crops. Perennial differ from annual crops due to their ability to recycle C and N from one year to another. The slow and permanent turnover of their root system and perennial organs plays a key role for C and N recycling in soils. We have developed a new version (v10) of STICS model in order to simulate new processes and increase the genericity of the model under diversified cropping conditions.

Results

The model has been developed, parameterized and calibrated for three perennial crops (Miscanthus, Lucerne and Switchgrass) during 4 years in the research units AgroImpact (Laon) and P3F (Lusignan). This work was realized with the supervision of members of the EPS team thanks to a steering committee. The first step, consisted in the conceptualization of new formalisms to simulate C and N cycling in perennial crops and to improve the genericity of the STICS model. After the validation of the new formalisms allowing the simulation of C and N fluxes at the scale of the growing season (Figure 1; Strullu et al., 2014), we analyzed the model behaviour under long term simulations.

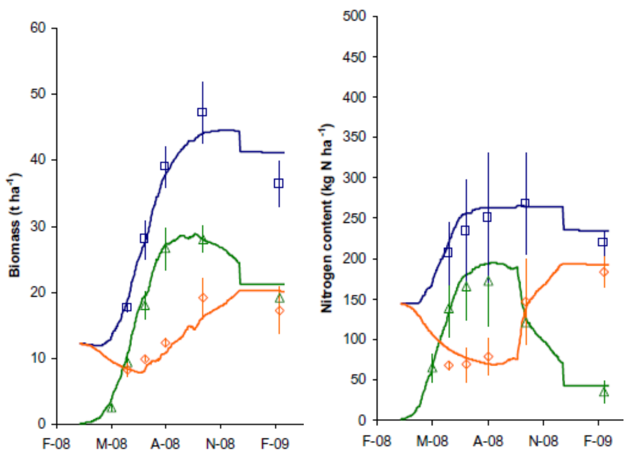

Figure 1: Simulation of biomass and nitrogen fluxes in perennial organs (orange), aboveground organs (green) and aboveground + perennial organs (blue) of Miscanthus.

When we tried to realize the simulation of successive regrowth of a perennial crop on the long term, the model simulated both a decrease of soil organic carbon and nitrogen stocks and an accumulation of mineral nitrogen in the soil. These results were in contradiction with experimental observations and literature. After a review of the literature, we decided to implement the simulation of the turnover of root system and perennial organs in the model, allowing the simulation of C and N recycling in soils. The new research version was evaluated against long term experiments with independent data (Figure 2). The model was then used to realize a yield gap analysis to study the effect of water and N stresses on Miscanthus biomass production (Strullu et al., 2015).

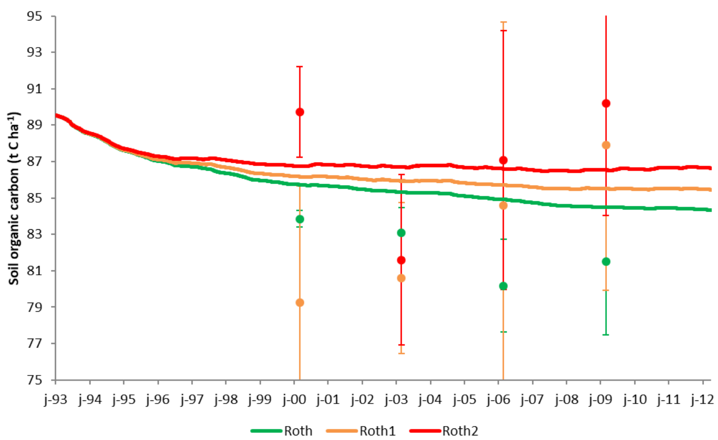

Figure 2: Simulation of soil organic carbon under Miscanthus on the long term at Rothamsted: comparison of 3 treatments. Roth: without N fertilization; Roth1: with 60 kg N ha^{-1} y^{-1}; Roth 2: with 120 kg N ha^{-1} y^{-1}.

The final step of this work consisted in evaluating the genericity of the model which was applied to other perennial crops like Switchgrass and Lucerne. We improved the genericity of the formalisms describing the C and N partitioning between organs by including structural and reserve compartments. Additional formalisms were required for simulation of Lucerne in order to take into account specificities concerning the effect of photoperiod on biomass and N partitioning (Figure 3; Strullu et al., 2020).

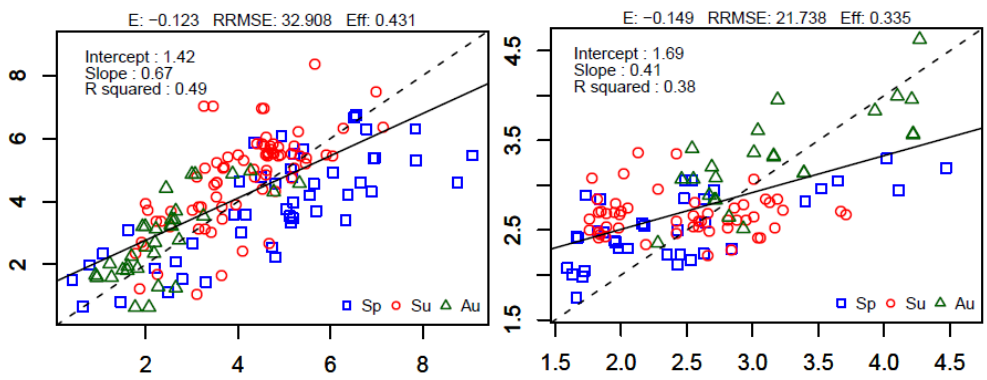

Figure 3: Simulated versus observed aboveground biomass (left) and its N concentration (right) at harvest in function of growing season. Sp = spring; Su = Summer; Au = autumn.

The detail of these new formalisms applied both to annual and perennial crops on the long term will be given in an updated version of the STICS red book (version v10) which will come out in 2020.

Références bibliographiques

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

SticsRpacks: a set of packages for managing Stics from R

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Keywords: R, model simulations, parameter estimation, uncertainty and sensitivity analysis

Introduction

The SticsRpacks project has been initiated end 2018 to develop tools for piloting the STICS model via the high-level language R. These tools aim at:

- easily performing operations that are not provided in JavaSTICS: e.g. production of various graphs, statistical processing, link with databases ...,
- automating these operations using scripts,
- reducing the computation time required to perform simulations.

It is composed of a set of R packages. These packages are addressed to Stics users and developers and will be used in its automatic test and performance evaluation system (Buis et al. 2016). Methodological packages are developed in a generic way to be coupled with other crop models.

SticsRfiles, SticsOnR and CroptimizR

First versions of the packages SticsRfiles, SticsOnR and CroptimizR (Fig. 1) will be released for the Stics 2020 seminar. Other packages may be developed later (e.g. IdeSticsR).

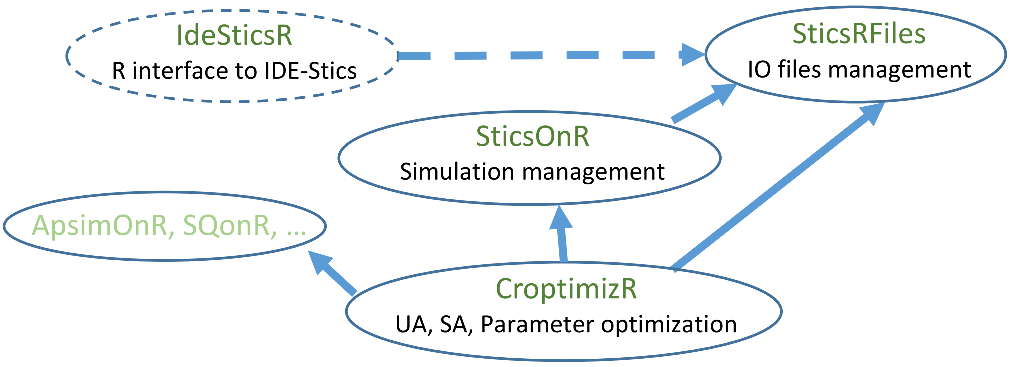

Figure 1. Architecture of the SticsRpacks packages. ApsimOnR and SQonR are external packages / functions. Development of IdeSticsR package has not yet started.

They will include functions for:

- converting XML input files (JavaStics) into text input files (Stics) ; replacing (getting) parameters and option codes values in (from) XML and text files ; getting simulated and observed variables values from Stics output and observation files (SticsRfiles package)
- generating Stics input files from JavaStics working directory ; running Stics simulations from JavaStics or Stics input files with possible forcing of input parameters / option codes and parallelization of the simulations (SticsOnR package)
- multi-step parameter estimations with frequentist (multi-start Nelder-Meade simplex, Nelder and Mead (1965)) or bayesian (DREAM, Vrugt (2016)) methods, with possible simultaneous estimation of specific and varietal parameters on multi-varietal datasets (CroptimizR package)

Development tools

StiscRpacks is a collaborative and opensource project. Source code versioning is handled in gitHub (https://github.com/SticsRPacks). A common coding style has been adopted. Automatic documentation is performed using Roxygen2. Websites are generated using pkgdown (see https://sticsrpacks.github.io/SticsOnR/, https://sticsrpacks.github.io/SticsRfiles/, https://sticsrpacks.github.io/CroptimizR/). User documentation is provided through function help and vignettes available on the packages websites. Automatic tests (including CRAN checks and unit tests) are performed using testthat and Travis.

Conclusion and perspectives

The development of the packages included in SticsRpacks just began. Other features are already planned and future versions should include additional functions for:

- downloading (uploading) USMs from (to) the IDE-Stics database (Beaudoin et al. 2015)
- converting (Stics input) text files into (JavaStics input) XML files,
- generating new USMs by combining existing climate, soils, plant and management files,
- analyzing crop models inputs and outputs (diagnosis, statistical criteria, graphics), including comparison with observations,
- probabilistic uncertainty analysis (multiple distributions and sampling methods) and sensitivity analysis (screening, importance measures, Multivariate Sensitivity Analysis, graphical Sensitivity Analysis, methods for dependent factors),
- other parameter estimation methods (e.g. evolutionary algorithm, Hamiltonian MCMC) and objective function criteria / likelihoods,
- selection of parameters to estimate,
- taking into account prior information and constraints (e.g. inequality constraints) on estimated parameters and output variables,
- evaluating the predictive performance in parameter estimation process (cross validation …).

In addition to Stics, CroptimizR has already been coupled with ApsimX and SiriusQuality crop models. Its genericity will make it possible to evaluate multiple calibration approaches on different crop models and pool crop modelling team efforts to provide relevant methods for users of those models.

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Session 2: New formalisms and crop calibration for crop diagnosis

Development of a new formalism for the establishment of grain yield and protein for determinate growing plants in a dedicated research version of STICS

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Keywords: grain yield, grain protein, formalism, sink/source, cereal crops

Introduction

The actual formalism of the STICS model (v9.1) for the prediction of grain yield, for determinate growing plants, consists in calculating a daily accumulation of biomass in grains by applying a progressive "harvest index" to the total biomass. This formalism brings a relative robustness in the yield prediction. According to the reference time unit used, it will give a higher weight to the use of carbohydrates produced after flowering (thermal time) or to remobilization (calendar time) for grain yield elaboration. This hinders the complexity and the dynamic of the different mechanisms that contribute to C accumulation in grain, especially within climate change context (Launay *et al*., 2010).

Material and methods

In a dedicated research version of STICS, we developed a new formalism that aims to consider grains as a sink, following Launay *et al*. (2010). The formalism to predict grain number was kept as the one used for determinate growing plants in STICS (v9.1). We replaced the formalism of total yield elaboration, and the *a posteriori* computation of the weight of one grain, by the filling of individual grains. The daily growth function of each grain proposed here corresponds to the derivative function of grain biomass growth evolution according to thermal time (Robert *et al*., 1999).

The lone source of water-soluble carbohydrate (WSC) is the temporal reserves, which are feed by remobilizations and the addition of neoformed carbohydrates during the reproductive phase. Although temporal reserves are not explicitly located in STICS, we know that the WSC are transported from the source to the sink through the phloem (Lemoine *et al*., 2013). We have therefore linked the flow of transpiration, due to stoma present in the leaves and spikelets, to estimate a daily flux. Knowing there is a maximal WSC concentration in phloem, we then introduce a daily limitation in the WSC availability for grains. Finally, the N content in grains is linked to the Nitrogen Internal Efficiency (NIE) as mentioned by Gastal *et al*. (2015).

Three experimental sites devoted to varying crop species (s. barley, w. barley and w. wheat), with treatments differing by N application and irrigation in the same site-year, were studied. These three experimental sites are the SOERE ACBB "Grandes cultures" (Estrées-Mons, France), Gembloux (Belgium) and Münchebger (Germany). We only used simulations with good aboveground biomass estimation to validate our formalism, since in our dataset we have no measure of temporal reserves.

Results and discussion

The comparison between model outputs shows a better prediction of grain yield and nitrogen content with the new formalism (Table 1). Focusing on the harvest index (HI) outputs between the actual formalism and the new one (Figure 1) shows a significant difference on either barley or wheat crops. The current formalism is not so robust since for a same year and a same site, the mean HI is underestimated and the variability of simulated HI is almost null. Using the new formalism improved both the performance of the mean prediction and a better account of the HI variability according to crop management. Especially, the new formalism was able to simulate the exceptional weather condition in 2018 with a high remobilization of neoformed carbohydrates during reproductive phase.

Besides the performance of production criteria, this research version is expected to better predict the C:N ratio of crop residues, which strongly influences soil mineral N availability and humus storage.

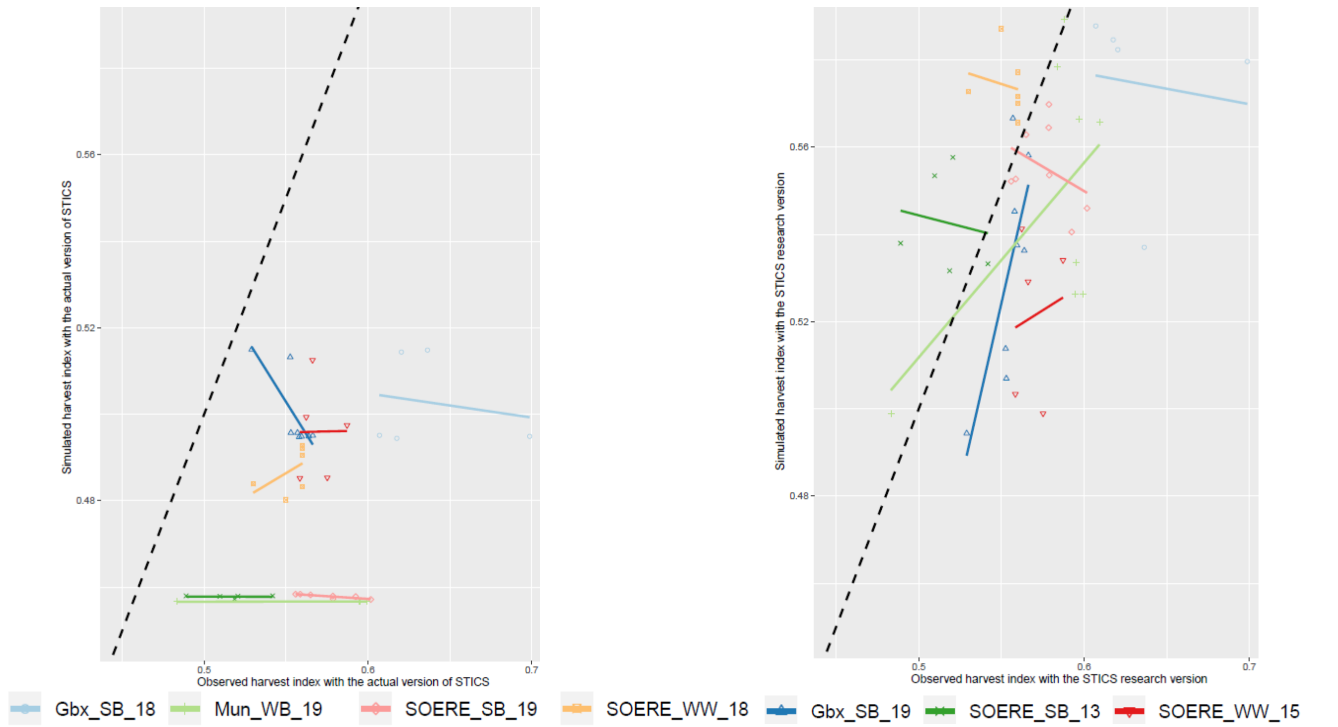

Figure 1. Comparison of the observed (x axis) and the simulated (y axis) harvest index between the actual (left) formalism and the new one (right). Group of datasets from Gembloux (Gbx, Belgium), Müncheberg (Mun, Germany) and Estrées-Mons (SOERE, France). SB, WB & WW stand for s. barley, w. barley and w. wheat respectively. Numbers 13, 15, 18 & 19 are the harvest year. Lines represent linear regressions.

Table 1. Efficiency of the model with the actual formalism and the new one on some variables during crop cycle

	Aboveground biomass	Aboveground N amount	Grain yield	Grain N amount
Actual formalism	0.83	0.49	0.33	0.15
New formalism	0.83	0.49	0.54	0.56

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Assessment of the impact of water stress on soybean yield in Canada using STICS

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Keywords: soybean, yield, water stress, evapotranspiration

Introduction

In Canada, soybean is grown mainly in Ontario and Quebec, without irrigation (Statistics Canada, 2019). Within one production region, average annual yields can vary considerably from year to year (up to about 60% variation in some regions, FADQ 2019). Several biotic and abiotic factors may explain these interannual variations, but it is difficult to assess the extent to which each factor contributes to these variations. However, it is likely that the intensity and temporal distribution of precipitation plays a major role within the abiotic factors. The use of long climate series (> 30 years) is one way to better understand the effect of climate variations on the yield of crops such as soybean. Since little or no experimental data are generally available over such a long period, the use of a crop model calibrated and validated for the region of interest is a relevant solution for this type of approach.

The objectives of this work are to 1) verify the performance of the STICS model in simulating the water balance of a soybean field (soil water stock and evapotranspiration); and 2) use the verified model to evaluate the impact of water stress on yield losses.

Materials and methods

Prior to this work, 22 data sets from the Ottawa area (Canada) were used to calibrate and validate soybean phenology, growth and yield processes in the STICS model (v 9.0). Of these 22 datasets, four (years 1997, 1999, 2008 and 2016) included evapotranspiration and soil moisture measurements. These four datasets were therefore used to evaluate the model's performance in simulating two of the main components of the water balance of an agricultural field during the growing season (Apr–Oct), cumulative evapotranspiration flux per 10-day period and temporal variation in soil moisture.

Once the model's performance was verified, several series of simulations over long periods (50 years) were carried out. Four sites located in Ontario (ON) and Quebec (QC) with significant climate gradients were selected for the study: London (ON), Ottawa (ON), Saint-Hubert (QC) and Quebec City (QC) from the site with the longest growing season (212 days) to the one with the shortest season (183 days). For each of these sites, independent simulations (not successive) were carried out using the historical climate years from 1960 to 2009 (50 years) for the three main soil types in each region. Finally, in order to better assess the impact of water stress, simulations were carried out with or without irrigation. A total of 1,200 simulations were carried out (4 sites × 3 soils × 50 years × 2 irrigation practices). Simulated yields for the St-Hubert site without irrigation were compared to the yields measured by La Financière Agricole du Québec (FADQ) between 1995 and 2009 to verify the performance of the model in simulating the average yield of a region and its interannual variability. Then, the simulation results were analyzed by site and then by site/soil.

Results and discussion

The soil water stock (*resmes* variable) is generally well-simulated, with a normalized root mean square error (NRMSE) of about 15% and a very low bias (1%). Soil water distribution is also well simulated, with NRMSEs between 12.6% and 33.8%. The highest NRMSE was obtained for the top soil layer (0–

10 cm). For decadal evapotranspiration, the model's performance was slightly worse, with a NRMSE of 35% for the 4 years combined. This lower performance of the model is particularly noticeable for 1999, with an overestimation of evapotranspiration (bias of 43.2%). For the other 3 years, the NRSME was close to or less than 30%, and the bias less than 20%. Overall, the model performance is therefore satisfactory, and it can be used to assess the impact of water stress on soybean yields.

The simulated average yield over the 1995–2009 period at the St-Hubert site is close to the average yield measured by the FADQ in this region (2.8 and 2.4 t ha^{-1}, respectively). The model's slight overestimation can be explained by its inability to take biotic factors into account. However, the interannual variability seems to be well reproduced by the model, with predicted yields ranging from 2.1 to 3.2 t ha^{-1} and from 2.0 to 2.9 t ha^{-1} for the measurements. The comparison of treatments with and without irrigation shows that on average water stress could reduce soybean yield by between 4.4% and 12.5%, depending on the site. The largest reductions are in Ottawa and St-Hubert (-8.5% and -12.5%, respectively), and the smallest are in London and Quebec (approximately -4.4%). As expected, the largest water stress yield reductions are simulated for the most sandy soils (sandy loam; yield reduction from -8.5% to -13.9%), since these soils have a lower available water capacity than loamy soils (loam, clay loam and silty clay loam). It should be noted that the impact of water stress seems very significant on the heavy clays of the St-Hubert region (-16.8%), which are also characterized by a relatively low available water capacity. Finally, the simulation results indicate that the interannual variability of yields due to water stress would represent about 28% of the total variability related to abiotic stresses taken into account by the model, with significant spatial disparities. Analysis of the standard deviation of simulated yields over 50 years indicates that water stress could represent nearly 45% to 48% of the variability in Ottawa and St-Hubert and only 8% to 13% in Quebec and London. For these two sites, temperature variations seem to be the cause of most of the interannual variability. Temperatures are often sub-optimal in Quebec City, and conversely there is a more significant frequency of days with temperatures above the optimum growth range in London, especially during the grain filling period.

Conclusion

The model was able to correctly reproduce two of the main components of the water balance of a soybean field in eastern Canada. Its use with long climate series on four sites and different soil types confirmed that water stress played a major role in the interannual variability of yields for two of the sites studied (Ottawa and St-Hubert). For the other two sites, most of the interannual variability in yields is probably explained by temperature.

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Comparison of sugarcane STICS model calibrations to simulate growth response to climate variability

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Mots clés : canne à sucre, La Reunion, calibration, ICSM

Keywords : Sugarcane, Reunion island, calibration, ICSM

Introduction:

The key role of crop models is to help understand and predict the effects and interactions between climate, soil, management, species facilitation and competition on crop development and yield. Several process-based sugarcane models have been developed, such as DSSAT-Canegro, Canesim, Mosicas, or APSIM-Sugar, which differ through the nature of input parameters and constituent process algorithms. Assuming that the choice of model should be questioned each time according to the desired application, we present here the calibration of a new growth model for sugar cane (STICS). This model is particularly suitable for studies on species associations or the agrosystem's response to the supply of organic matter residues.

In the present study, we present and compare three different calibrations of the sugarcane crop growth in STICS, each of which can be applied to a different situation and objectives:

- Cane stalk conceptualized as a grain, in order to simulate sugar yield (STICS v9): “Sugarcane_grain”
- Cane stalk conceptualized as a stem, in order to simulate fresh cane yield variability (STICS v9): “Sugarcane_stem”
- Cane with perennial reserves, in order to simulate multiple regrowth (STICS vX): “Sugarcane_regrowth”

Methods:

The database used for calibration consisted in 8 trials performed in the ICSM projects. These trials, described in Jones et al. 2019, included 2 years of sugarcane monitoring in four countries (Reunion, South Africa, Zimbabwe and USA) and followed the same measurement protocols. Additionally, 6 trials performed in Reunion between 1994 and 1997, used for the initial sugarcane prototype calibration, were used.

In the present study, we choose to parameterized the sugarcane species using field measurements or measurements in the literature as a priority. In cases where this information was not available, the model parameters were calibrated. The calibration was performed using an R package (Rgenoud) with a genetic algorithm and a RRMSE like scored function. The trials available in the ECOFI database (Christina et al., 2019) were used as a set of validation. This database includes 95 trials (1988-2018) performed with the R570 variety in Reunion Island.

Results & Discussion

An illustration of STICS simulations on the ICSM trials is presented in Figure 1. All three calibrations (“Sugarcane_grain”, ”Sugarcane_stem” and “Sugarcane_regrowth”) satisfactorily simulated the leaf area index, and carbon allocation to aerial, leaf and stalk dry mass in the ECOFI trials. The “Sugarcane_grain” was currently the only one accurately simulating sugar yield in the cane stalk, but it failed to simulate fresh cane yield, which is an essential information for farmers and sugar industries. The “Sugarcane_stem” was the most accurate calibration to simulate fresh cane yield and thus should be applied to yield forecast studies. Finally, the “Sugarcane_regrowths” had strong potential, while simulating fresh cane yield and potentially sugar yield (still under development). Additionally, the possibility to simulate multiple regrowth with STICS vX could make it possible to assess the yield decline with ratoon age commonly observed by farmers as the evolution of soil organic matter in function of agricultural practices.

Perspectives

The potential applications of the STICS model for sugarcane simulations will be discussed with two focus on sugarcane / legume associations, and sugarcane response to organic residue applications.

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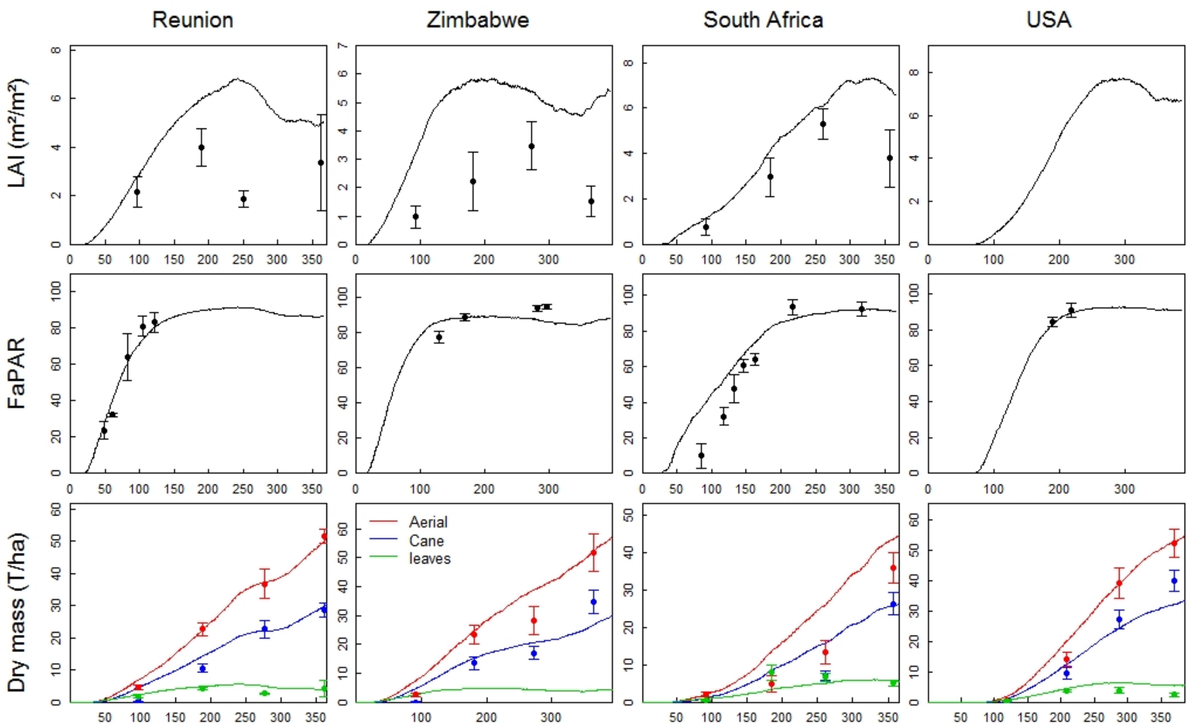

Fig 1. Example of simulations obtained with the STICS model in the ICSM project (“Sugarcane_stem”).

Use of the STICS model for simulating physiological and soil evolution in the Champagne vineyard under different scenarios

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Keywords : vine, physiological balance, soil water and nitrate content, Champagne vineyards

Introduction

These last few years, the champagne vineyard appears as a real case study for the evolution of nitrogen and water availability. In fact, among other nitrogen stress indicators, the must nitrogen has been decreasing since the 2000s. The combination of restricted mineral fertilizers and herbicide use, the growing variability of spring rainfall, the increasing thermal stress as well as the soil type heterogeneity are only a few underlying factors that trigger loss of physiological balance in the vineyards. The use of crop modelling approaches in order to accurately follow the nitrogen, carbon and water cycles within the vine and the soil, especially for future scenarios, appears necessary. The first part of the study consists in validating the STICS model parameterization for vine (Garcia de Cortázar-Atauri, 2006) under the Champagne vineyard conditions. The second part formalizes the use of the STICS model for the Champagne industry.

Materials and Methods

The STICS model v9 was used in this study. Two dataset were mobilized for this study. The first dataset was obtained using the “réseau vigueur” which is a network of 6 plots representing champagne’s vineyards variability in terms of soil, climate and viticultural practices. A large set of physiological and soil measures are operated since 2017. The second is a historical database on the experimental station of the Comité Champagne in Plumecoq which provides leaf water potential and leaf area data.
The validation and parameter optimization processes were operated using the EvalR and Optimistics tools of the STICS interface, in a specific non-interchangeable order: first on soil and then on physiology parameters, mostly water in fruits. The simulations were validated at each step with observed data using mostly the root mean square error.

Results and perspectives

Optimization of 5 parameters and validation of the model in the Champagne vineyards

Observed and simulated leaf water potential at Plumecoq showed at first a very high RMSE as the subsoil chalk, not considered by the model, positively impacted the vine water status. We therefore modelized this chalk by adding two hypothetical horizons with a wilting point at 25% and a field capacity at 40%. We then optimized, under this chalk subsoil context, 4 soil parameters: pebbles (cailloux), soil humidity at field capacity (HCCF), initial root density (densinitial) and the depth of root obstruction (obstarac), enabling to reach lower RMSE for leaf water potential and leaf area.
The next step consisted in optimizing the harvest date, thus the yield simulation, through water status in fruits with two parameters: H2Ograinmax (maximum water content in berries at harvest) drawn out of brix degrees values at harvest and deshydbase (phenological rate of evolution of fruit water) which was optimized on Pinot Noir variety, using the observed harvest dates. The harvest dates RMSE decreased a lot, the leaf area index appeared very well simulated with an RMSE of 0.66, but the yield simulation remained unsatisfactory (RMSE of 1.25) impacting the aboveground nitrogen content as well (RMSE of 23.49) (fig.1).

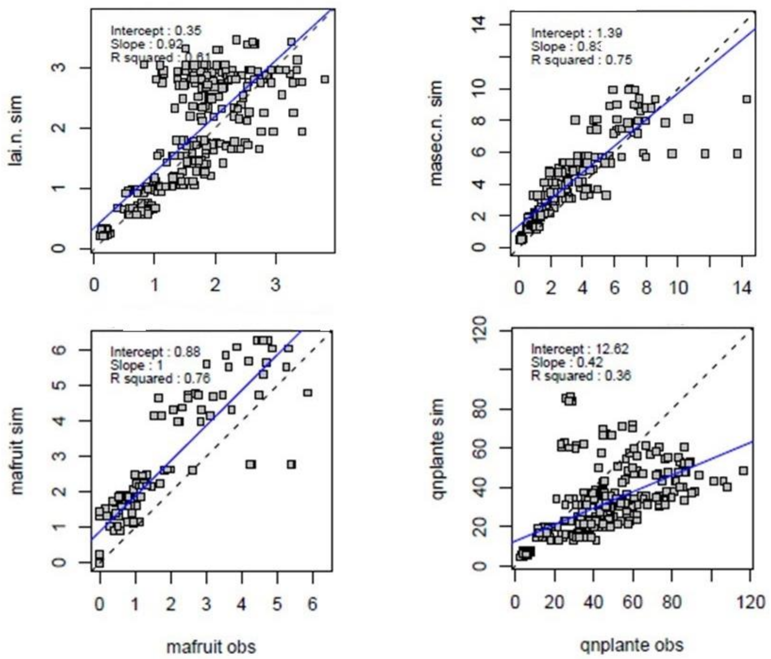

Figure 1: Comparison of simulated and observed data for leaf area (lai), aboveground biomass (masec), yield (mafruit) and aboveground nitrogen content (qnplante) on the "réseau vigueur" database in 2018 and 2019 on 42 unit simulation model (USM).

The use of the STICS model in Champagne

Predictive climate scenarios for 2019 were created from the 15th of June and onwards in a given type of soil (fig. 2). Decadal mean climatic data ('2019 prévi') was compared to past climatically "extreme" vintages (1997, 2002, 2016 and 2018) in order to see the range of values the nitrate content in soil could reach as well as the period of nitrate retention in the first 30 cm during autumn, a crucial timing for vine reserve storage.

The use of the STICS model in the champagne vineyards is not to predict yields or harvest dates but rather to foresee the evolution of some important soil and vine indicators impacting the vine physiological balance yearly and through hypothetical future scenarios. The perspective of a web intranet portal is explored by the Comité Champagne providing information about leaf area, phenology, soil water and nitrate status using Champagne's meteorological station network and soil typology.

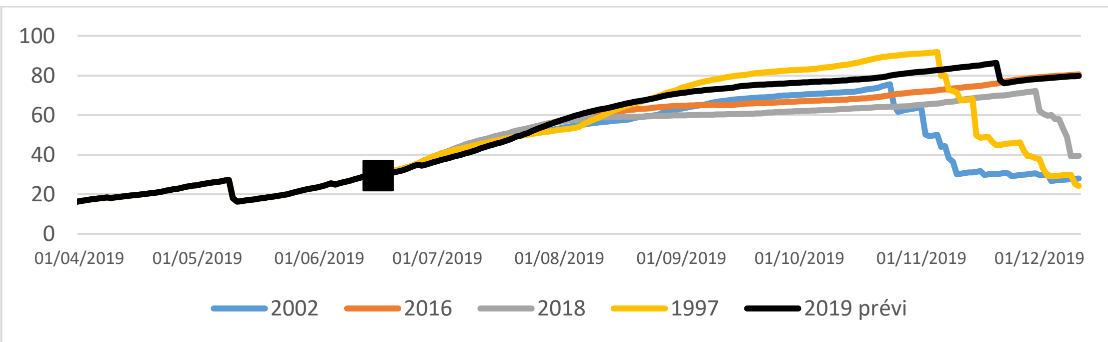

Figure 2: Nitrates dynamic simulated by the STICS model, in kg/ha within the first 30 cm of soil.

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Session 3: Modelling intercropping with STICS

How to model crop-weed competition for soil resources: Connecting the STICS soil submodel to the FLORSYS weed dynamics model

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Keywords : weed, competition, nitrogen, water, cropping system, multicriteria evaluation, crop diversification

Introduction

Weeds are harmful for crop production but essential for biodiversity. Process-based weed dynamics models are crucial to synthesize knowledge on weed dynamics and crop-weed interactions, apply this knowledge to cropping-system design and transfer it to stakeholders. Such models can also help to analyse the effects of crop diversification (longer rotation with more species, cover crops, crop mixtures) which crucial for agroecological crop production. Indeed, the processes driving crop-weed interactions are the same for crop-crop interactions in crop mixtures and crop rotations. Plant-plant competition for soil resources plays a key role in these interactions. This paper illustrates how we connected the soil submodel of STICS (Brisson *et al.*, 2009) to provide soil-resource inputs for the weed dynamics model FLORSYS and then how we used the resulting "model complex" for simulations.

Connecting the STICS soil submodel to the weed dynamics model FLORSYS

FLORSYS (Colbach *et al.*, 2014; Colbach *et al.*, in revision) is a virtual field for which the user enters a list of cultural operations lasting for several years (crop succession including cover crops and crop mixtures, all management techniques), together with daily weather, soil properties and a regional weed species pool (Figure 1). These inputs drive the biophysical processes in the field at a daily time step, with a 3D individual-based representation of the canopy. FLORSYS focuses on processes leading to (1) plant emergence and establishment of crop and weed species with diverse ecological requirements (which allows for crops sown in different seasons and in mixtures where timing determines the fate of a species); (2) the functioning of heterogeneous crop-weed canopies including diverse plant ages, morphologies and shade responses (as in crop mixtures); (3) carryover effects in terms of, e.g., weed seed bank, soil organic matter or water content on future cropping seasons (which is crucial for crop rotations). The detailed biophysical model outputs are aggregated into indicators of crop production and weed (dis)services to easily compare cropping systems. Figure 1 illustrates how this model was connected to the STICS soil submodel. The source code of the two models remains sufficiently separate to allow easily connecting future versions of STICS to FLORSYS.

Evaluation and design of multi-performant cropping systems with simulations

First, we simulated virtual farm-field networks based on farm surveys from different regions and stakeholders to identify weed-suppressive crop ideotypes and cropping-system types that reconcile low yield loss with low herbicide use. The simulations showed that, compared to crop species with a high yield loss due to weeds, low-loss crops present a larger plant width per unit biomass in unshaded conditions, thinner leaves to increase leaf area, chiefly from flowering onwards, and etiolate when shaded by neighbour plants, with taller plants per unit plant biomass and even thinner larger leaves. Three "winning" cropping-system types were identified: maize monocultures and 2 types with diverse rotations (different species, both winter and summer crops, intercropping, temporary grassland) and/or crop mixtures, combined with well-reasoned tillage (stale seed bed, occasional ploughing).

FLORSYS was also used to assess cropping systems designed by scientists or farmers in workshops. Farmers appreciated the model's ability to (1) predict weed (dis)services over several years, (2) determine probabilities of success or failure of innovative strategies as a function of past field history and weather scenarios, (3) identify biophysical explanations of cropping system performance, (4) fine-tune cropping systems to local conditions. The workshops led to major take-home messages on agroecological weed management for farmers, e.g., assess crops at the rotation scale, weather and inadequate crop management can cancel out the effects of beneficial techniques, weed floras do not disappear but change…

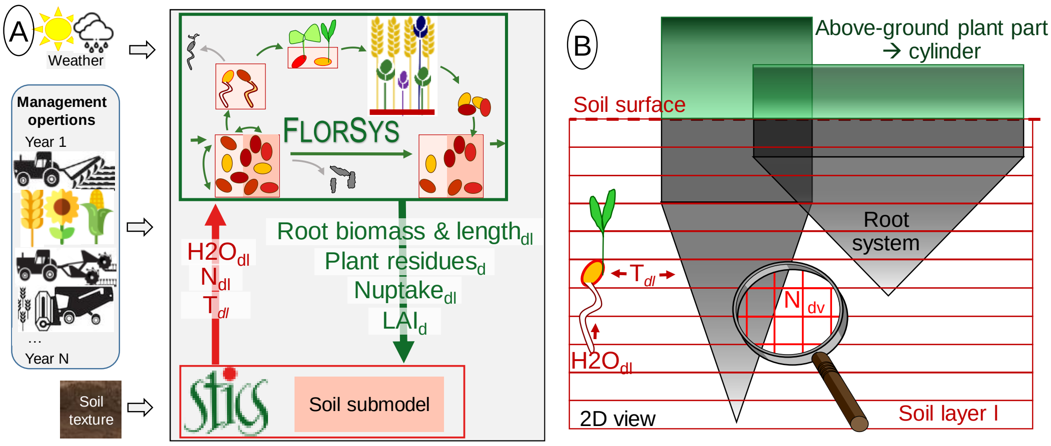

Figure 3. Connecting the STICS soil submodel to the 3D individual-based FLORSYS weed dynamics model. A. Each day d, STICS provides water potential, nitrogen availability and temperature for each soil layer l. These drive seed and plant processes in FLORSYS, together with weather and cropping-system inputs. FLORSYS returns canopy information to STICS to calculate soil variables for the next day. B. In FLORSYS, soil temperature and water potential drive seed germination and pre-emergent growth, soil temperature drives root-system growth. Available nitrogen is distributed inside soil voxels (3D pixels) in each soil layer and extracted by the roots inside each voxel.

Conclusion

This study showed how a STICS submodel was connected to a 3D individual-based multiannual weed dynamics model. The resulting "model complex" can simulate contrasting cropping systems with different soils, weather scenarios and weed floras. This is essential to establish rules for weed management depending on the production situation and cropping system.

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Improving the intercropping version of the STICS model for simulating inter-specific competition

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Keywords : soil-crop model; wheat; pea; interspecific competition; intercropping; ecological intensification

Introduction

The STICS model has been previously adapted to simulate crops grown in bi-specific mixtures (Brisson et al., 2004; Launay et al., 2009), but the model evaluation showed inconsistencies regarding light interception, plant height, frost damage and leaf senescence for intercrops as partly already identified by Corre-Hellou et al. (2009). The main objective of our work was to update the intercrop version of STICS by fixing code issues and by adding new formalisms to integrate a computation of plant height and a new formalism of the equivalent plant density to better represent the competition between the two crops. A second objective was to evaluate the relevance of these changes compared to the previous version using a comprehensive dataset of field measurements.

Materials and Methods

The new computation of plant height uses an allometric equation from the aboveground biomass that enhances the range of possible relationships while being robust and parameter scarce. A new option was included for the equivalent plant density, a concept first included by Brisson et al. (2004) to consider the interspecific competition between two species. The code of the model was also revised to remove some bugs, mainly for the computation of frost damage and leaf senescence, that were found for the intercrop version. The model STICS was then evaluated using observations from durum wheat and winter pea grown either in sole crop or bi-specific intercrop in Auzeville (France) for three years in 2007, 2010 and 2011. The new parameters were calibrated using the sole crop data, except those only used for intercropping, for which two parameters were calibrated using data of intercrops. Then, the simulated leaf area index (LAI), aboveground biomass and plant height were compared to measurements at different growth stages for each species, either in the two sole crops or in intercrop, in order to evaluate the improvement with respect to the previous model version.

Results and discussion

The simulations from the new STICS-intercrop version were closer to the observations compared with the previous version of the model for the targeted output variables, i.e. LAI, aboveground biomass and plant height for the three wheat-pea intercrop experiments (Fig. 1). The RMSE was lower by 15.8 % on average for the two species and the three variables, and the model efficiency increased from -0.27 to 0.53 showing that the new formalisms improved the simulation of the intercropping system. The model is currently being tested more extensively using different N-treatments, species and pedoclimates to define its validity domain, with preliminary results presented in Paff et al. (2020). A new R package that uses the STICS intercrop version was designed and used to perform simulations and analysis (Vezy et al., 2019). See the SticsRPacks project for more information (Buis et al., 2020).

Conclusion

New formalisms were implemented in the STICS-intercrop version to model bi-specific intercrops with a relatively simple conceptual approach simulating competition for light capture between two intercropped species. The new version successfully simulated LAI, aboveground biomass and plant height for both wheat and pea grown either in sole- or in intercropping.

Acknowledgements

This work was funded by the ReMIX project, a EU's Horizon 2020 Program.

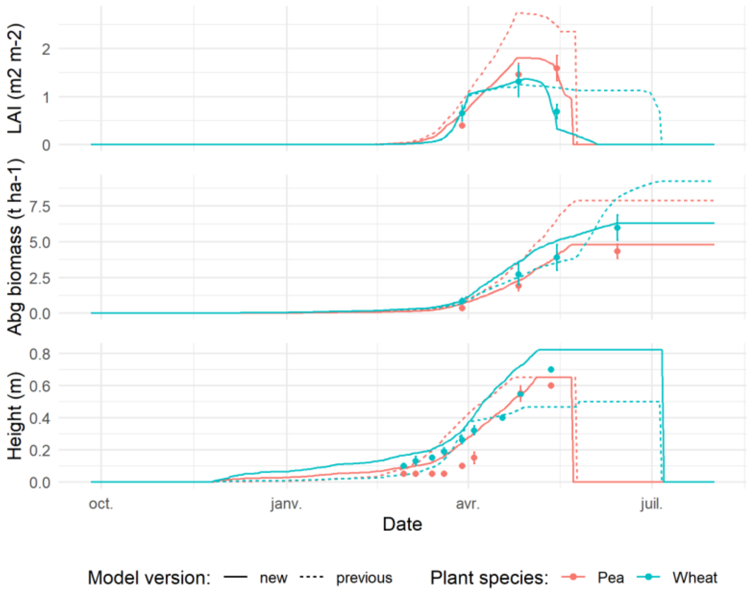

Figure 4. Simulated (lines) and observed (symbols) leaf area index (LAI), aboveground biomass, and plant height for pea (red) and wheat (blue) grown in mixture simulated with the previous (straight) and new (dotted) STICS-intercrop version.

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Calibration and Evaluation of the STICS Intercrop Model for Two Cereal-Legume Mixtures

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Mots clés : Intensification écologique ; modèle de culture ; Pois ; Orge ; Blé dur

Introduction

STICS is a soil-crop model capable of simulating crops in succession (Brisson et al., 2003). Intercropping occurs when multiple species are grown simultaneously on the same field. There has been a growing interest in adapting this traditional technique for modern agriculture as a way of ecological intensification, especially for combining leguminous and cereal crops in order to reduce N inputs and potential environmental damage through N losses. Intercropping adds complexity to the system by adding inter-species competition. Crop models are useful tools for analyzing complex systems, as they allow the user far more control over individual variables than is possible in field experiments. A first version of the STICS intercrop model was created by Brisson et al. (2004) and was recently improved by Vezy et al. (2020). The aim of this study was to calibrate and evaluate this improved STICS-Intercrop model by simulating a winter and a spring intercrop mixture: durum wheat-winter pea and barley-spring pea.

Materials and Methods

The data set used for modelling comprised of four years of wheat (*Triticum turgidum* L.) and pea (*Pisum sativum* L.) field data from Auzeville, France with multiple levels of nitrogen fertilizer, and four years of barley (*Hordeum vulgare* L.) and pea field data from Angers, France (Corre-Hellou, 2005), which in some years included two levels of nitrogen fertilizer and two different plant densities of the intercrops. The sole crop trials were used for calibration and the intercrop trials for evaluation, except for a subset of intercrop data that was used to calibrate the parameters unique to the intercrop model. The assumption was that parameters common to both sole and intercropping, such as plant-soil interactions and phenology, would be the same for both. The optimization method used for calibration was based on Wallach et al. (2011). The parameters were broken down into 15 groups (16 for pea to include nitrogen fixation) for calibration, each corresponding to a different process.

Results and Discussion

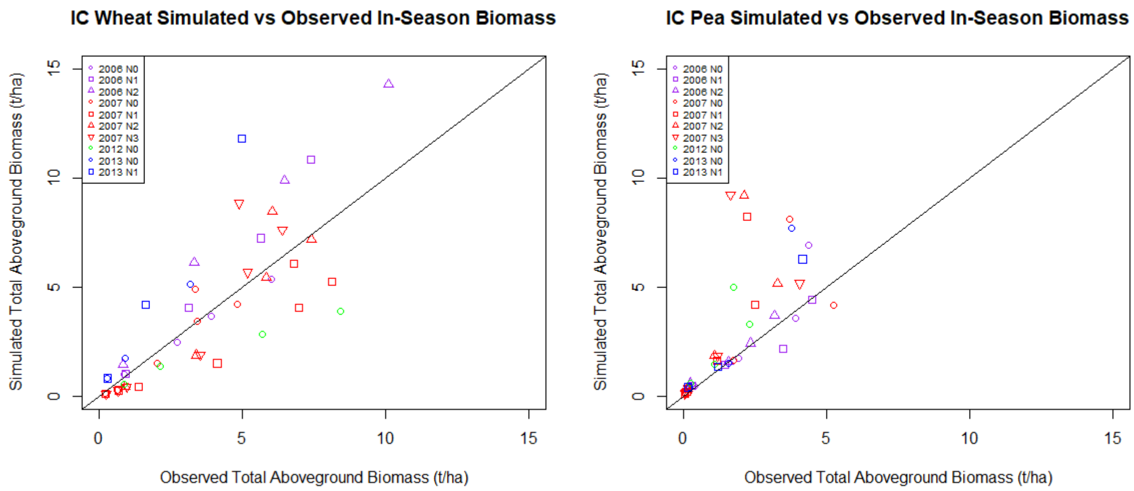
The root mean square error (RMSE) for shoot biomass was 1.92 t/ha for winter pea and 1.37 t/ha for durum wheat. The RMSE for grain yield was 1.84 t/ha for spring pea and 1.15 t/ha for barley. Overall the model captured the dominancy of one species quite well, however the accuracy has to be increased. The phenology and height were correctly simulated. Some of the discrepancies could be due to biological stresses that STICS does not capture. The modelling efficiency is likely to improve because the model calibration process is still ongoing, especially for the pea-wheat simulations.

Conclusions

The intercrop version of the STICS model was recently improved. An automatic calibration was performed in this study using two different crop mixtures, several years and multiple nitrogen treatments to assess the capacity of the model to simulate these complex systems. The model performed reasonably well considering the wide range of conditions on which it was calibrated. STICS intercrop could be a useful tool for better understanding the processes and their interaction for this management practice.

Acknowledgments

This work was funded by the ReMIX project, a Research and Innovation project from the EU's Horizon 2020 Program. Special thanks to Nadine Brisson for beginning the work on the STICS intercrop model. We also thank Marie Launay , Dominique Ripoche, and Patrice Lecharpentier for their work on the model.



(a) (b)

Figure 1: Simulated versus observed in season total aboveground biomass for wheat (a) and pea (b) grown in intercrop with each other at Auzeville, France.

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Modelling the agronomic performance of millet-cowpea intercropping under the semi-arid environment of Senegal

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Keywords : Cropping system, pearl millet, cowpea, model, performance, variability

Introduction

In the Sahel, particularity in Senegal, pearl millet ([*Pennisetum glaucum* (L.) R. Br.], is one of the major cereals constituting the bases of the population's subsistence. However, its production faces several constraints leading to extreleley low yields (Affholder et al., 2013), including the low nutrient content of the soil, especially nitrogen (Badiane, 1993). Added to this is the high inter-annual variability of climate, the high cost of inputs and the low an inter_annually variable price of grain making conventional crop intensification risky and poorly profitable economically. The intercropping pearl millet with cowpea is expected to promote better management of arable land thanks to a land equivalent ratio (LER) greater than 1, i.e. the by improving the yield of the associated crops as compared to sum of the yields of sole crops using the same amount of land (Obulbiga et al., 2015). Given the complexity of the variability of the responses of these intercrop depending on the soil and climate contexts, the use of modeling is a less costly and less time-consuming method than experimentation, which makes it possible to understand how the intercrop works and to test scenarios of the intercrop in order to improve its functioning. A fundamental aim of the experiment was to simulate different scenarios in the context of climate change in order to obtain optimal production of pearl millet while improving the physico-chemical conditions of the soil through the use of different sources of nitrogen (chemical fertilizers, intercropping system and mulching). Specifically, this involves studying the effect of fertilization, mulching and association (and density of cowpea seedlings) on the development and yield of pearl millet and cowpeas; to assess the effect of the combination of different nitrogen sources on soil physicochemical properties and crop yields; to study the agronomic performance (LER) of the intercropping pearl millet-cowpea and its inter annual variation according to the combination of the different nitrogen sources and at the end of calibration, validate the StiCs model. This is a work of which only the experimental part is today completed and in this communication we only present the methodology of our project and the very first data analyzes that we were able to carry out with the StiCs model.

Material and methods :

The trial was conducted at the National Center for Agronomic Research of Bambey, Senegal, during the wintering 2018 and 2019. The experiment was set-up as a complete random block design with a factorial structure in strictly rainy conditions and with additional irrigation.

The factors studied were fertilization, cropping system, sowing density and mulching. Pearl millet, souna 3, cowpea, Baye Ngagne and 58-74f were used. The data from these experiments will be used to calibrate the StiCs model first, also using the literature to configure the characteristics of the species in our study. Then we will evaluate the model by comparing the observed dynamics to those simulated so as to verify what gives us the model, to understand and predict the dynamics and finally perform virtual simulations in a context of climate variability, in order to evaluate the performance of these systems in the future.

First results

The literature review and the data from the 2018 experiments allowed a first calibration of the thermal constants of the Stics model to reproduce the phenology and LAI of cowpea and millet in pure culture.

Conclusion and continuation of the work: The data obtained during these two years will allow us to assess the agronomic performance of the associated mil-cowpea crops in different contrasting fertilization situations and to calibrate the model.

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Calibration and evaluation of the STICS soil-crop model for sorghum-cowpea intercrop in sub-Saharan Africa

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Introduction

Intercropping is an entry point for sustainable agricultural intensification, particularly for the variable rainfall conditions that prevail across sub-Saharan Africa. However, deriving relevant recommendations for intercropping management requires field experiments. The time, cost and technical skills required to study the temporal production of intercropping systems using field experiments is likely to limit the number and duration of multi-years trials (Lobell et al., 2009). To address such limitations, crop simulation models have been used to assess the agronomic and environmental performances of cropping systems under diverse climatic conditions, including hypothetical future climate (Boote et al., 1996). Intercropping has not been modelled extensively and models that simulate these cropping systems, such as STICS, have not often been evaluated for tropical conditions and for species grown by farmers in sub-saharan Africa. The objective of this study was to evaluate the performance of STICS model adapted for West African conditions to simulate the growth and productivity of sorghum-cowpea cropping systems.

Material and method

We used the STICS soil-crop model and data from field experiments conducted at the N'Tarla Agronomic Station in Mali in 2017 and 2018. Two varieties of sorghum (local and improved) with different photoperiod sensitivity were grown as sole crop or intercropped with cowpea. Two sowing dates and two levels of mineral fertilization were also investigated. Model simulations were evaluated using observed data for phenology, leaf area index (LAI), biomass, yield and soil moisture. The performance of the model was evaluated using root mean square error (RMSE) and model efficiency (EF).

Results

So far, the calibration has been performed for sole crops only. After calibration, the model satisfactorily simulated sorghum phenology (RMSE = 3.38 days for flowering and 3.41 for maturity). Cowpea phenology was less well simulated (RMSE = 13.27 days for flowering and 9.30 for maturity). Model simulation were satisfactory for soil moisture (RMSE = 14%, EF = 0.72) and aboveground plant biomass (RMSE = 39, EF = 83). With current calibration, the model underestimated the leaf area index with RMSE of 49% and EF of 0.46.

Conclusion

Our work provides a first calibration and evaluation of the sole crops involved in the sorghum cowpea intercropping under rainfed conditions in southern Mali. The next step of the work will be to calibrate the intercropping treatments.

Keywords: Crop model, Biomass, Leaf area index, Water use efficiency

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Session 4: Methods and new tools for modelling with STICS

AgGlob: Workflow for simulation of agronomic models at a global scale

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Keywords: Crop modeling, Computational modeling, Parallel computing, Global simulation.

Introduction

Simulation of biophysical models over large areas is used in different contexts linked to global agronomy issues (Müller et al., 2017). It is useful for analyzing crop performances at a regional scale (Shelia et al., 2019), for estimating vulnerability of crop production to climate change (Elliot et al., 2014, Montella et al., 2015)... One of approaches is Global Gridded Biophysical Models (GGBMs). It consists to use a crop model developed at field scale and to run it on different sites in order to take into account the heterogeneity of soils, climates and farming practices over the area. The sites are organized according to a spatial grid, with a fine resolution (some km^{-2}). It is possible to run these massive simulations thanks to the development of clusters. It is also possible because more and more data are available to characterize soil, climate and farming practices at fine resolution. Nevertheless, many difficulties remain. They concerned i) the coordination of the actors involved in the process of production of results, ii) the heterogeneity of data formats that makes tricky to reuse them iii) the design and the realization of the campaign of simulations, iv) the validation of simulation results by automated tests, v) the reproducibility of results and traceability, vi) methods and visualization tools suitable to the mass of results to analyze. To overcome these problems, we propose the AgGlob framework, based on a workflow developed on a Galaxy platform instance. (https://galaxyproject.org/).

Materials and Methods

A workflow consists in a sequence of treatments where each step is dependent on occurrence of the previous step. The first treatments concern the access to data stored in external databases and their processing in order to make them compatible to the crop model. For this step, we have developed basic bricks of the workflow.

- *"Climate data" tool*: access to datasets composed of daily observations of temperature, radiation, rain and PET. These data are provided under conditions by SICLIMA database, (INRA climate series provider). The SAFRAN grid is used (Meteo France standard with a resolution of 8km). Queries and post-processing are automated.
- *"Soil data" tool*: access to BDGSF (French Soil Geographic Database) maintained by Infosol (INRA provider). An SQL query requests the data. It puts the data into the format expected by the crop model.
- *"Land use" and "Farming practices" tool:* All the information concerning soil land use in France and farming practices come from the national surveys: "French Land Parcel identification system" and "Enquêtes pratiques agricoles". The information are stored in ODR database (INRA provider) and aggregated at the grid scale. The objective is to have for each cell of the grid, the most representative i) soils, ii) rotations and iv)farming practices. All these layers of information are combined based on the conceptual work done in INRA study "Evaluation Française des Ecosystèmes et des Services Ecosystémiques" . The results is a table where each line corresponds to a point to simulate with all the information required for simulation (crop rotation, sowing date …) on a concise form.

The second step of the workflow consists in preparing the campaign of simulations with the bricks:
- “Simulation Campaign” tool: The previous table is transformed into a text file. The user can download and modify it, in order to design a new simulation campaign (scenario). The tool includes algorithms for testing the validity. Then, this text file is sent to the parallelization service of RECORD simulation platform (Bergez et al., 2014), embedded in the tool.
- “Crop simulation” tool: The model used is STICS encapsulated in RECORD (Bergez et al., 2014). It runs the campaign simulation on the cluster.
The third step concerns the post-processing of simulation results, with automated checks of simulation results, and the production of indicators.

Results and Discussion
AgGlob is available on an INRA Galaxy instance. It is connected to a distant cluster (Meso@LR) where the simulation jobs are run. It includes a formalization of GGBMs campaign simulation, that we consider as a standard reusable in other projects. A campaign of simulations generates large amount of results. Some consistency checks have been integrated in order to help the user in detecting problems. The workflow can be plugged on other Galaxy instances.

Conclusion
AgGlob is an interesting framework for GGBMs simulation. It helps in coordinating the actors involved, because the different steps of processing are clearly identified and formalized. It also offers a solution for the integration and aggregation of data necessary for simulation, by using automated processing algorithm. It is enough generic to be easily extend to other crop models and to other data. It is also an implementation of the FAIR principles in the domain of GGBMs work, therefore it enhances the reproducibility and traceability of results.

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Preliminary coupling of STICS (v9.1) to PEcAn ecological informatics toolbox, and its comparison to BASGRA

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Keywords: Process-based models, cyberinfrastructure, informatics, uncertainty

Introduction

Process-based simulation models are useful tools to study natural systems, and support our efforts of understanding their dynamics and making decisions about their management. For the case of agricultural systems in particular, these models can help us manage agricultural lands in a way that enhances their carbon sequestration potential and role in climate change mitigation (Paustian et al., 2016). However, making predictions and performing complex analyses with these models are not always easy. Process-based agricultural models typically require drivers, initial conditions, parameter files and detailed settings for a single model execution, often in model's unique formatting specifications. Likewise, each model produce outputs in their specific formats, variable names and units. Although these models usually come with documentations for enabling new users to set up their working environments, they often end up being accessible to only a small group of users who has considerable programming experience. Even within the modeler community, these models are often operated with custom made functions that are executed manually, whose results cannot be easily reproduced even by the person who created them. Thankfully, modeling groups are increasingly supporting their models with helper functions or packages to overcome these difficulties. However, these helpers also have individual learning curves and they are usually not compatible with other models. Instead, integration of models with community cyberinfrastructure tools by developers could greatly increase the accessibility of these models to a wider audience within the ecological and environmental community. As a result, the models could be tested by more people at more sites against more data. This is important because each model essentially embodies different hypotheses about how natural systems work and performs differently under different conditions. Community tools can help us perform multi-model predictions, explore the range of possible outcomes, determine the areas where we lack process understanding, benchmark/select/average models more readily, in a reproducible manner.

Methods

Towards this goal, we coupled STICS (Simulateur mulTIdisciplinaire pour les Cultures Standard, Brisson et al., 2003) model to one such community cyberinfrastructure, PEcAn (Predictive Ecosystem Analyzer - LeBauer et al., 2013; pecanproject.github.io). PEcAn is an open source ecological informatics software that consists of common tools for model execution and analysis. PEcAn communicates with a PostgreSQL database called BETYdb (LeBauer et al., 2018) in the background throughout the modeling workflow, and uses a unique identifier for each workflow. These IDs make all settings and related metadata that went into the modeling workflow accessible and transparent to others. A model is coupled to PEcAn workflow through a few wrapper functions that control the data stream in and out of the model. Currently, there are more than a dozen of process-based models coupled to PEcAn. To couple STICS to PEcAn, we leveraged the SticsRPacks (github.com/SticsRPacks) functions. This preliminary coupling allowed us to hand the control of model's operation over to PEcAn where the automated workflow pre-processes the input data, runs the model, post-processes the output data, and assesses model performance. PEcAn framework uses Bayesian approach and treats model parameter and initial condition uncertainty as probability distributions. We ran STICS for a grassland farm in Finland where micrometeorological data, biomass and yield data, and eddy covariance measurements have been recorded since 2018. We propagated the parameter and initial condition uncertainty for this site to model outputs by ensemblizing model runs, and performed an uncertainty analysis. However, we note that, under current coupling neither all STICS nor PEcAn functionality are enabled. For example, not all the optimizable parameters of STICS are varied (have a prior on them) yet. Likewise, PEcAn's state data assimilation (SDA) module can assimilate observations into models using the Ensemble Kalman Filter algorithm, but SDA-couplers (two additional functions that stop and restart model in between assimilation cycles) for STICS are still under development. For this site, we additionally ran another process-based model, BASGRA (BASic GRAssland model, Höglind et al., 2016), which is also coupled to PEcAn. We compared the prediction of these two models using PEcAn's benchmarking tools against flux data.

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A global optimization tool for assimilation of leaf area index into STICS crop model

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Keywords : Global optimization, assimilation of LAI, STICS, Earth observation.

Introduction

The assimilation of leaf area index (LAI) derived from Earth observation (EO) data is an effective approach to improve yield predictions. Assimilation can be done by re-initializing some input parameters such as seeding date, seeding density, and soil moisture at field capacity, which are not readily available (Jégo et al. 2015). The performance of assimilation techniques are, however, affected by the method used for optimization and its ability to find a global solution. Thus, there is a need to develop a user-friendly global optimization tool for crop modeling applications.

Material and methods

We introduce a new global optimization package (global optimization for calibration and assimilation, GOCA) under which various optimization approaches embedded in MATLAB global optimization toolbox are integrated with the STICS crop model. The package is compiled with MATLAB compiler which makes it an standalone package for users with no MATLAB. GOCA loads information related to simulation units (e.g., name of climate, soil, and observation files) from a spread sheet, which can be modified by users. The spread sheet also contains information related to optimization bounds for variables. Furthermore, GOCA allows users to select the optimization techniques with related settings. The approaches included in the package are Patternsearch, Particle Swarm, Simulated Annealing, and Surrogate.

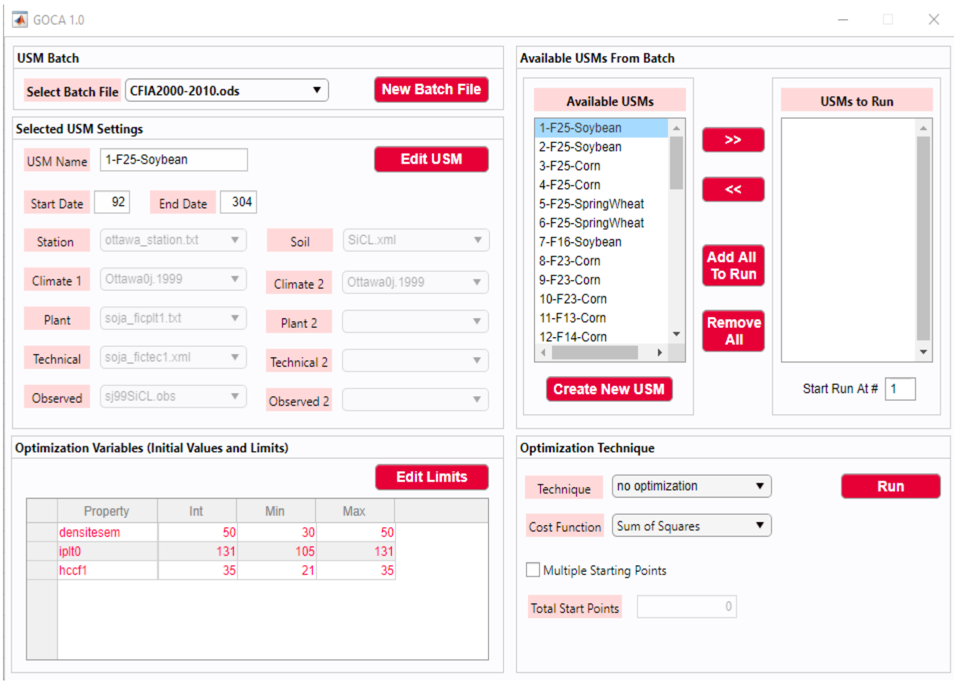

Figure 1. a view of GOCA optimization package

Results

To examine the performance of different optimization techniques, a study was conducted in a small experimental farm in Ottawa (ON, Canada), planted with soybean, corn, and spring wheat during 1999 to 2010. The simulation units were obtained by overlaying the field boundaries to soil map. EO data were acquired from various sources: 3 to 9 images for 1999 to 2008 from multi-spectral images (Landsat or SPOT) and airborne hyperspectral images (CASI); 13 images for 2010 from multi-spectral Formosat-2. LAI was retrieved from MTVI2 (Haboudane et al., 2004) and EVI2 (Huete, 2002) derived from the EO data (Liu et al. 2012). The optimization setting were set at default values and the maximum iteration were set at 20 iterations for techniques that allowed for such settings. We compared different optimization techniques with the simplex approach in JavaSTICS (Table 1). All methods embedded in the GOCA package outperformed the Simplex approach embedded in JavaSTICS in both yield and LAI prediction.

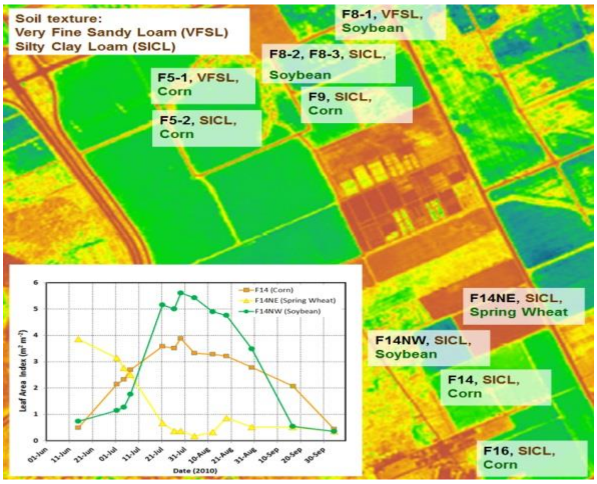

Figure 2. Information on soil texture, crops, and field locations. LAI extracted from Formosat-2 images in 2010 are also illustrated for 3 fields.

Tabel 1. Performance of different optimization methods.

Optimization Technique	Run time[1] per simulation (second)	Yield		LAI	
		ME%	RMSE%	ME%	RMSE%
Simplex (JavaSTICS)	25 seconds	-12.97	26.75	10.97	52.25
Surrogate	25 seconds	-0.08	23.05	-5.91	52.30
Simulated Annealing	7 hours	-2.25	24.17	1.41	46.03
Particle Swarm	8 minutes	7.51	20.74	1.35	41.61
Patternsearch	25 seconds	-6.03	18.92	1.58	41.62

[1]The computer CPU information for these runs was: Intel® Core™ i7-6600U CPU @ 2.60 GHz

Surrogate, Simulated Annealing, and Particle Swarm approaches are stochastic approach, whereas Patternsearch and simplex are deterministic. While the run time of Patternsearch was the same as Simplex, it provided better performance. Among stochastic approaches, Particle Swarm outperformed others with reasonable running time (e.g., 7 minutes per simulation unit). The performance of Particle Swarm approach also outperformed others in predicting seeding date, seeding density and soil moisture at field capacity.

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STICS on SIWAA: A STICS Tool set deployed on the SIWAA Galaxy Web platform

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Keywords : Virtual Research Environment, Crop Simulation Model, Simulation Workflow

Introduction

In many cases of virtual scientific experiments or studies, collaborative development of workflows of simulations on appropriate computing resources, is essential. Like the FACE-IT [1] framework did propose his Web portal to support the AGMIP [2] Project, the SIWAA [7] framework is a new Galaxy Web Platform that intent to support the AgGlob [6] Project.

In this paper we outline some of the main requirements the SIWAA platform aims to address, describe the architecture, present the early Stics [4] tool set, outline the integration process, and propose future direction for the involved teams and users.

Requirements

We propose her the two main requirements we address in priority.

access to computational resources : Even if either academic or commercial computing resources are available, many users do not have enough skills or time to implement efficient virtual experiment on a high performance computer. And This difficulty is increased when the members of a project do not have access at the same computing resources and for the same periodicity. Therefore the access to computational resource should be given and permanent.

sharing active pipeline of tools : As soon as researcher collaborate to develop a virtual experiment chaining the execution of softwares, they can face many difficulties, like complex installation procedures, personal workspace heterogeneity, versioning of data and softwares, persistency and serialisation of the pipeline. One of the solution is to centralize the deployment of the softwares on a central system accessible by the web.

Architecture and Services

SIWAA is fully based on the Galaxy Web platform [3] providing a simple uniform and extensible workflow authoring and execution interface that enable to develop workflows of simulation in collaborative way. The design of the deployment of Galaxy we have achieved is in two parts. On one side the Web server is running on a simple Linux Virtual Machine hosted by the INRA services at Toulouse, and at the other side we have configured the system to run computing Jobs on the High Performance Computing Center MESO@LR [8].

In order to gives to the authors of the tools a complete access control, we do provide a tool access management system based on the concepts of groups and roles already available. And according to their economics resources users can also use specific computing account that they can decide to by at MESO@LR. Furthermore, we can enable the users to parametrize by them self the computing resources they want to get from the High Performance Computing Center.

The tool delivery process we decide to adopt oblige the authors of tools to package each tool and publish them on our own Toolshed, service also provided by Galaxy. Nevertheless in order to be efficient and flexible, we allow two kind of packaging. Either you can package the classic way by providing scripts where component dependencies are solved by the CONDA [11] packaging system, or you can package by providing a command line referencing a Docker [9] container, that will be executed by Singularity [10] on the HPC.

A Stics tool set

In order to validate the operational capability of the SIWAA platform, according to the GEOC project founded by the INRA we decide to focus on the development of suite of tools enabling some use cases of the Stics Models:

- OptimizeStics9.0: enables to optimize a set of Stics parameters according to situations and observations, based on on SticsRPacks [5] embedded inside a Docker container, is parallelized.
- SimulateStics8.50 & SimulateStics9.1: simulate one or many Stics Workspaces in parallel, with or without a plan, based on simple scripts calling the Stics simulatior embedded inside a Docker Container.
- ConvertStics8.50 & ConvertStics8.50: convert Stics Xml Workspaces to Stics Workspaces runnable by the Stics Command Line Interface.
- MorrisGrid & MorrisGridIndices: provide a Morris experimental plan, and compute the result of a sensitivity analysis, based on the SticsRPacks.
- WaterStatus and WaterStatusAtFlowering: provide graphical outputs convenient for the OPERATE[13] project, implemented with R Scripts.

Conclusion

SIWAA is a new infrastructure designed to facilitate the sharing of active virtual experiment and the access to a HPC system. By providing a first tool set dedicated to the Stics model, we have demonstrate our capability of feeding the system with promising applications. We will now be facing new goals like hosting new simulators, and factorizing companion tools and data usages, and this in order to contribute to the animation of a SIWAA user community.

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A new method for sensitivity analysis of models with dynamic and/or spatial outputs

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Introduction

Global Sensitivity Analysis (GSA) is recognized as a powerful tool for measuring the impact of models inputs on simulated outputs under prescribed inputs' variability. Although many simulation models, among which crop models, produce temporal and/or spatial data, extracting relevant information from GSA of such outputs is still challenging. This requires the use of Multivariate Sensitivity Analysis methods (MSA) that are often based on a dimension reduction principle: model outputs are projected onto predefined or data-driven orthogonal bases such as polynomial or eigenvectors (Lamboni et al., 2011). They are however so far limited by the selection of the associated bases which is constrained by orthogonality requirements. Indeed, these bases do not always allow extracting relevant and interpretable information on structural properties of multivariate outputs. More applicable MSA methods are thus expected to be developed (Wei et al., 2015). In this work, we propose a new MSA method combining GSA and clustering.

Cluster-based GSA

Clustering methods have been designed to identify groups of similar objects in multivariate data sets. They may thus be particularly adapted to capture the variability of behaviors of models' temporal and/or spatial outputs. However, while binary clustering has been extensively used in scalar sensitivity analysis to assess the importance of factors leading to a region of interest (Raguet and Marrel, 2018), there is still a lack of quantitative sensitivity analysis methods taking benefit of a clustering of multivariate outputs with any number of clusters.

The main idea of the proposed method is to apply clustering to model outputs simulated on a numerical design-of-experiment generated using a given GSA method, and to compute standard GSA indices (e.g. Sobol' indices) not on the models outputs but on new variables indicating the membership of each output to the different clusters (see Fig. 1). We propose to use a fuzzy clustering method: the new variables are thus the so-called membership functions (MF, valued in [0, 1]) that quantify the degree of membership of any model simulated output to each cluster. The computation of sensitivity indices on either the MF or MF differences allows discussing which parameters influence the membership to a given cluster or drive the output from one cluster to another. A generalized sensitivity index (Lamboni et al, 2011) is also introduced to quantify the overall contribution of the parameters wrt any change of clusters.

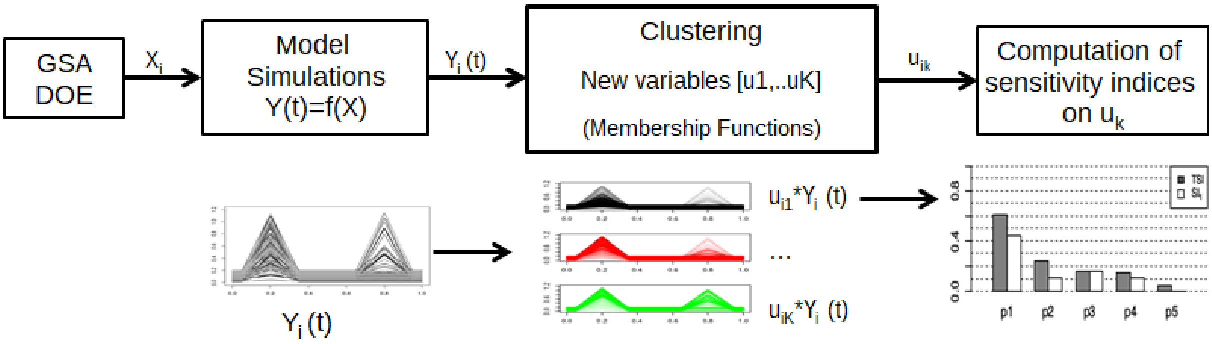

Figure 1. Workflow of the Cluster-based GSA. X represents the vector of model inputs that varies in the sensitivity analysis, Y(t) the (temporal in this case) output simulated by the model. K is the number of clusters, i the index in the design-of-experiment.

Applications

The method has been applied using Sobol' and FAST GSA methods to:

(i) a dedicated toy model producing temporal signals with one or two maxima in response to five parameters,

(ii) the Cantis model (Garnier et al., 2003) simulating the transformations of carbon and nitrogen in soils (10 parameters varying),

(iii) the Stics crop model (Coucheney et al. 2015), on the Multi-Model Ideotyping Agmip 2019 exercise (27 parameters varying).

Results have shown that the model behaviors can be efficiently reported by the newly proposed method.

Conclusions

The proposed method is particularly adapted to models with dynamic and/or spatial outputs that produce distinguishable sets of responses, i.e. when clustering of these outputs lead to well separated and interpretable clusters. In this case, it is particularly powerful for identifying the model inputs that drive these different behaviors. The method is generic wrt clustering and GSA method used.

Keywords
Sensitivity analysis, multivariate outputs, generalized sensitivity indices

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Session 5: Environmental impact of cropping systems and soil C&N dynamics

Verification and long-term simulations of STICS crop model to predict and analyze growing seasons N_2O fluxes of spring wheat in eastern Canada

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Keywords : greenhouse gas emissions, nitrogen fertilization, rainfed crop

Introduction

Capturing the variability of nitrous oxide (N_2O) fluxes during the growing season in response to synthetic fertilizer application and climate variations is quite challenging for process-based models. Indeed, nitrous oxide fluxes are very sporadic and heterogeneous. This variability is not well captured yet in the inventories based on emission coefficients. Verifying process-based model prediction of N_2O emissions is a top priority if we want to reduce the uncertainty in our regional and global estimates and if we want to make sound assessments of beneficial management practices over space and time.

Material and Methods

The STICS crop model can simulate the soil–crop system with a daily time step by individual year (i.e., with annual reinitialization) or linked over multiple years to account for crop rotation (i.e., no annual reinitialization). The daily N budget takes into account mineralization, denitrification, nitrification, NH_3 volatilization, and crop N uptake. Recently, new nitrification and denitrification formalisms (Bessou et al., 2010) were added to STICS crop model to estimate N_2O emissions, based on experimental results collected mostly from western Europe. Denitrification and nitrification are assumed to occur in the biologically active layer (i.e., 30 cm in the present study). The N_2O predictions of STICS were evaluated against field-scale fluxes measured using micrometeorological towers equipped with a tunable diode laser to measure fast-response N_2O gradients. The N_2O fluxes were measured in spring wheat (*Triticum aestivum* L.) fields (Ottawa, ON, Canada) during 5 growing seasons between 2001 and 2014. The experimental fields were tiled drained and had homogeneous soil properties (silty clay loam and clay loam soil textures). Different mineral N fertilization rates (40-80 kg N ha^{-1}) and forms (urea, ammonium nitrate) were applied. The study focused on growing season N_2O emissions following mineral fertilization, which were divided between the vegetative and reproductive stages. In humid climate regions such as eastern Canada, nitrous oxide emissions are mostly driven by denitrification and to a lesser extent by nitrification. After completing the model performance verification with annual reinitialization, long-term simulations (1953-2012) were performed at Ottawa and Quebec City for three N fertilization rates (100%, 80% and 60% of the recommended N rate) and on two contrasted soil textures (sandy loam and clay loam in Ottawa; sandy loam and silty clay in Quebec City). Simulation results were analyzed to evaluate the impact of climate variability on N_2O fluxes.

Results

Overall the STICS model predictions were in the same range than the observations for each growing season, except for 2014 resulting in a normalized root mean square error of 25.4% for all years and 11.5% when 2014 was excluded. Model predictions were usually smaller than measured values for the vegetative stage when denitrification was dominant (mean error of -0.26 kg N ha^{-1}). During the reproductive stage, the predictions were closer to the observations (mean error of 0.06 kg N ha^{-1}). The best results were obtained in 2005, when a dry spell occurred during the vegetative stage. Although the temporal dynamic of N_2O fluxes was not always well captured by the model, the satisfactory results obtained for cumulative emissions over the entire growing season allowed to perform long term simulations over 60 years using the STICS model.

As expected the long-term simulation results showed that N_2O fluxes were greater on more clayed soil and for the higher N fertilization rates. The N_2O fluxes of the recommended N fertilization treatments were 15 to 32% greater than those of the treatments with 60% of the recommended N rate. The N_2O fluxes were also greater in Quebec City (47°N) than in Ottawa (45°N), as a result of the more humid climate favorable to denitrification processes. In Ottawa, the fluxes during the vegetative stage were mainly controlled by the N fertilization rate. On the other hand, the fluxes during the reproductive stage were not affected by fertilization rate, but a strong linear relationship was found with cumulative precipitation (R^2 ranging from 0.48 to 0.65). These results could be explained by the fact that in the spring, during the vegetative stage, soil moisture was usually high and soil nitrate was then the main factor controlling soil N processes and N_2O fluxes. In summer, during the reproductive stage, soil moisture was much more variable and became the main factor controlling soil N processes and N_2O fluxes. Weaker similar results were found in Quebec City for the sandy loam soil (R^2 ranging from 0.23 to 0.28). However, on the silty clay soil texture no clear relationship between precipitation and N_2O fluxes was found, most likely because soil water retention was greater for this texture in response to the elevated precipitation. Further analyzes are planned to evaluate the effect of growing degree-days and crop growth on N_2O fluxes.

This study showed that the recent improvement of the STICS crop model allowed to simulate quite accurately the cumulative N_2O fluxes during the growing season under variable climate conditions of eastern Canada. Accurate simulation of soil moisture during the reproductive stage and soil mineral N content during the vegetative stage were found to be critical for obtaining accurate predictions. The next phase of the project will be to evaluate the model performance over the entire year, from spring crop seeding until the next spring crop seeding, thus including winter with snow cover and the high N_2O emission period following snow melt and spring thaw.

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Modelling decomposition and N_2O emissions of mulches varying in quantity and quality

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Keywords: mulch, residue decomposition, carbon, nitrogen, N_2O emissions

Introduction

Conservation agriculture promotes permanent soil cover with plants or crop residues. This practice is already widely adopted in the subtropical part of Brazil and worldwide (field crops, perennial or semi-perennial crops). The decomposition of crop residues left on soil surface is a complex process, driven primarily by chemical composition (or quality) of residues, environmental conditions, and soil-residue contact. Changing the quality of residues results in changes in the rate of decomposition and mineralization of nutrients. The amount and morphology of residues determines mulch thickness, which influences how soil surface moisture and temperature are in turn affected. All these changes also affect nitrous oxide (N_2O) emissions from nitrification and denitrification, which are strongly affected by inorganic N, labile C and soil water status. Field experiments to evaluate the whole spectrum of mulch scenarios would require considerable time and resources. Simulation models such as STICS have the potential to help in the evaluation of this whole range of possible scenarios as they allow to explicitly describe the link between mulch characteristics, crop residues decomposition and N_2O fluxes. However, remaining gaps in the detailed knowledge of how mulches decompose still limit the predictive use of models. Recent experimental results had for example challenged the widely used hypothesis of a double compartment mulch decomposition model, in which a decomposing layer of limited thickness in contact with the soil is feeded by an upper non decomposing layer. In this context, the objective of the present study is to use specific *in situ* experiments with mulches varying both in thickness and quality to evaluate and improve the ability of the STICS model to simulate the decomposition and N_2O emissions of crop residues left at the soil surface. This should help for residue management in no-till systems in southern Brazil.

Experimental data and simulation methodology

The dataset used comes from two field experimental studies carried out in Santa Maria, Brazil (29°42'44" S, 53°42'74" W, about 90 m elevation). The local climate is of humid subtropical type (Köppen Cfa). The mean annual temperature is 16.1 °C and average annual precipitation is 1660 mm. The soil is a Typic Paleudalf with 110 g kg^{-1} clay, 260 g kg^{-1} silt and 630 g kg^{-1} sand in the 0-10 cm layer. The first study (Pinheiro et al., 2019; Dietrich et al., 2019) followed N_2O and NH_3 emissions during a sugarcane growth cycle on treatments with different straw quantities (0, 4, 8 and 12 t DM ha^{-1}) returned to the soil surface and two N fertilizer rates (0 and 100 kg N ha^{-1} as urea). Mulch decomposition, soil moisture, soil temperature and soil inorganic N over 0-10 cm depth were measured several times during the experiment. The second study (Schmatz et al., submitted 2019) followed over one year the decomposition and N_2O emissions of mulches of vetch and wheat added on a bare soil at different rates (3, 6 and 9 t DM ha^{-1}). Soil surface moisture and temperature were daily monitored during all the experimental period using sensors. Mulch decomposition and soil inorganic N were measured several times during the experiment. A step-by-step approach was defined for the simulation exercise, which was conducted using the STICS model v9.1. Simulation results were first evaluated for the bare soil treatment to check for correct simulation of soil temperature, soil water content, basal soil mineralization and N_2O emissions. Then the different mulches were simulated and mulch decomposition rates were evaluated for different hypothesis regarding the thickness of the mulch decomposing layer. The effect of the different quantity and quality of mulch on soil water content, C and N dynamics and N_2O emissions were then analyzed. Only the results from the second experiment are presented here.

First results

Small changes to the STICS general parameterization of soil evaporation were necessary to improve soil water dynamics simulation in the 0-5 cm and 5-10 cm layers for the bare soil. An increase in basal soil mineralization and a decrease of the potential nitrification rates improved a lot the simulated CO_2 fluxes and soil mineral nitrogen dynamics, both without and with the mulch. Changes in the order of magnitude of CO_2 fluxes with different mulch amounts and nature were particularly well reproduced. The first simulation results also indicated that over the range of mulch amounts considered, much better results were obtained by considering that the whole mulch layer is decomposing, and not only the lower part of it in better contact with the soil. Finally, introduction of a double component denitrification potential defined as the sum of a constant soil contribution and a variable component depending on residue decomposition rate and composition allowed to reproduce well the order of magnitude and dynamics of N_2O fluxes (Figure 1).

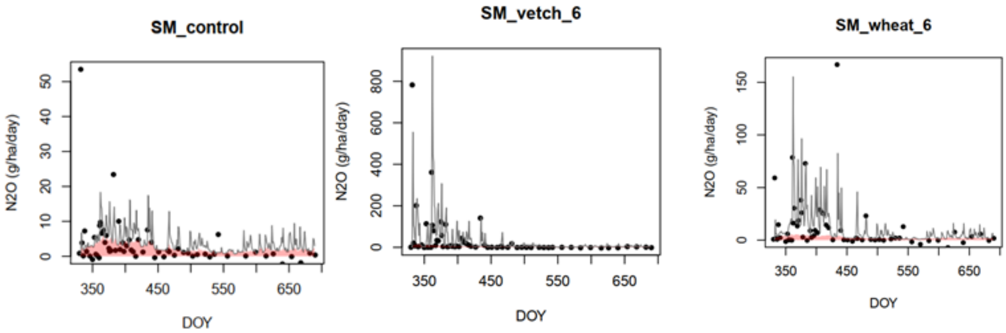

Figure 1. Observed and simulated dynamics of N_2O emissions for the bare soil and two different mulches of 6 ton/ha (vetch and wheat).

Acknowledgements

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Modelling short and long-term nitrogen and carbon budgets of agro-ecological cropping systems with a dedicated STICS research version

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Keywords: cropping system, conventional farming, organic farming, long-term, perennial organs

Introduction

Coupled studies of carbon (C), nitrogen (N) and water cycles address several issues: increasing carbon storage in soils (integrating C and N stoichiometry constraints), reducing greenhouse gas (GHG) emissions and ensuring aquifers refill despite increasing soil water deficits. But, the performances of agro-ecological systems facing these issues must be evaluated. Conducting assessments using a deterministic model raises the question of its ability to predict N mineralization/immobilization turnover due to residues decomposition, particularly dead roots materials.

The STICS model has already been used to simulate multi-services catch crops (CC) long-term impacts. However, the actual standard version (9.1) cannot simulate perennial species within rotations including also annual crops while a dedicated research version of the model can do it. It takes into account the symmetry between C and N plant compartments including perennial reserves, the daily dynamics of the root system and its turnover (and associated C and N fluxes), as well as specificities of perennial crops. For this study, we used a specific release of this research version (number 1610) but it is still under development and will be merged in a future STICS standard version.

This abstract describes the performances of this research version applied to four different cropping systems at different time scales, particularly with conventional (CONV) and organic (OF) cropping systems. The assumption made to extend STICS to organic farming was that its formalisms are still valid if weeds, pests and diseases are sufficiently well controlled (Autret *et al*., in press).

Results and discussion

In an OF field context, where alfalfa is partially used as green manure, the prediction of the soil mineral nitrogen (SMN) stock by continuous simulations, without any calibration, was successful (Figure 1). The model could simulate the development and growth of alfalfa, from seedling to destruction, with a unique corpus of formalisms and parameters (Strullu *et al*., 2020).

The model was used to simulate long-term (1977-2015) datasets obtained with seven undisturbed lysimeters monitored by INRA in CONV systems at Fagnières (France). It predicted satisfactorily soil organic nitrogen (SON) stocks, after three soil parameters have been calibrated against two other lysimeters (Figure 2). Crop yields, exports and drained water quantities were also well predicted (Yin *et al*., 2020). Leaching was underestimated by 37% in cropped lysimeters but not in the bare fallow lysimeter. However, the simulation of the nitrate leaching reduction allowed by CC was correct.

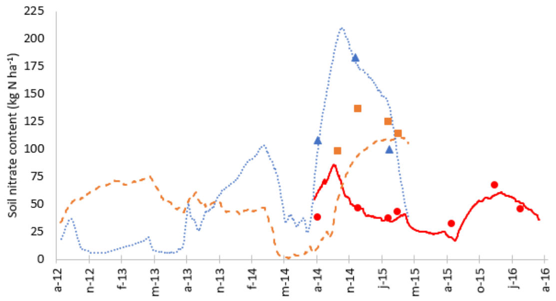

Figure 1: Observed and simulated SMN (kg N ha^{-1} in 0-150 cm) during cropping and after alfalfa destruction in 3 OF fields at Villotran (red), La Neuville/Oudeuil (orange) and Rubempré (blue triangles) (Strullu et al., 2020).

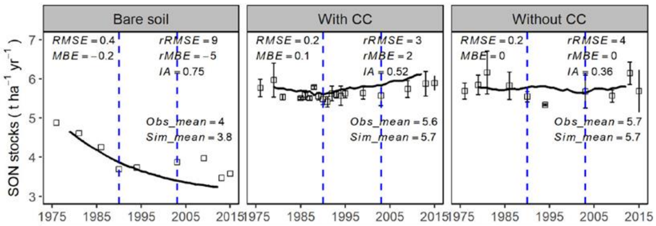

Figure 2: Observed and simulated evolution of SON stocks (0-25 cm) in Fagnières lysimeters. Treatments: Bare soil, with and without catch crop (CC). Vertical bars indicate the variability between three lysimeters (Yin et al., 2020).

STICS was applied to two long-term experiments including OF: DOK trial (Switzerland), 1977-2016 and Foulum experiment (Denmark), 1997-2017. After calibration of two soil parameters using each CONV treatment, the model gave correct predictions of yields, exportations and N surplus in OF treatments (Autret *et al.*, 2019). SMN was underestimated by 41%, but few data were available for testing. The observed decrease of SON was very well reproduced by the model. This decrease was consistent with the fact that the N surplus was negative or close to zero, depending on the treatment (Figure 3).

In the three long-term trials (Fagnières, DOC, Foulum), underestimation of either nitrate leaching, which is known to be linked with SMN, or SMN itself, was almost equal to simulated nitrogen stock in deep dead roots. The model does not simulate yet deep roots decaying below active biological layer (usually below 30 cm). This lack is being a science front.

This version has already been used in projects of 4‰ SOC storage (INRA-DEP) and alfalfa production (Variluz - CASDAR). It was also used in studies of leaching in the Seine basin, OF systems co-design, and C storage with grasslands, in respectively Gallois et al., Beaudoin et al., Cadéro et al., (*this conference*).

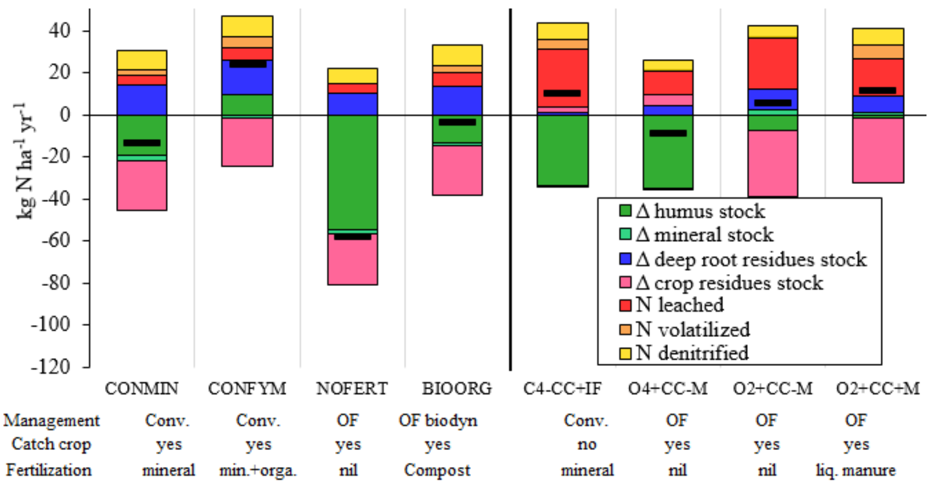

Figure 3: Simulated N surplus and its components (SON variations and NO_3 leaching losses or NH_3, N_2 or N_2O emissions) on 4 treatments of each long-term trial of DOK (Thervil, Switzerland, left) and Organic (Foulum, Denmark, right). Autret et al., (in press).

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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 in soils is well recognised but difficult to quantify as it depends on many environmental and agronomical factors. Modelling crop-grassland rotations can help quantifying the evolution of soil organic carbon (SOC) for a diversity of soils, climates, crops and managements, but it requires that models are sufficiently robust and accurate in their prediction of SOC. This study aimed to assess the STICS model ability to simulate long-term SOC dynamics in crop-grassland rotations. It is part of the French CarSolEl project.

Material and methods

STICS was tested against data from a 27-year experiment located at Kerbernez in western Brittany (France) and including nine crop-grassland rotations. Rotations A and B were silage maize monocrops. Rotations C, D and E were silage maize-Italian ryegrass rotations, with Italian ryegrass being established respectively for 6, 18 and 12 months between two-silage maize. Rotations I and J were respectively permanent and temporary perennial ryegrass grasslands established between two silage maize. Rotations Dd and Ed were only differing from respectively D and E by their rotation head. Crops were established on a 1m-depth loamy sand and slightly acidic soil, differing somewhat between rotations by the initial SOC stock (80-85 t C ha^{-1} in 0-25 cm). Rotation A received only mineral N fertiliser. All other rotations also received bovine then pig liquid manure. Both Italian and perennial ryegrass were only cut. The experimental area was cut in half in 1992. We used a research version of the STICS model (release 2485) able to simulate rotations including grasses and other perennial crops (Autret *et al.*, 2019; Strullu *et al.*, 2020). The model was run continuously from 1978 to 2004. Available observed data were crop DM yields, crop N contents, SON and SOC stocks at different dates. STICS was evaluated using common indicators for validation of biophysical models. A score was attributed to each simulation unit using a method derived from Kersebaum *et al.* (2015) and based on the information source, the number of repetitions and the observed factors that the model does not account for (e.g. weeds). This first evaluation included a revised parametrisation of perennial ryegrass.

Results and discussion

STICS well predicted the evolution of SOC stocks in rotation A (Figure 1, Table 1). However, it overpredicted final SOC for rotation B and silage maize-Italian ryegrass rotations. This could be partly due to an overestimation of the humified carbon from pig slurry inputs. STICS prediction of SOC under temporary (rotation J) and permanent (rotation I) grasslands was acceptable with final SOC conversely slightly underpredicted. Silage maize yields were globally overpredicted. It is partly explained by the fact that the model did not account for the observed detrimental effect of *Solanum nigrum* presence on silage maize yields (results not shown). Model prediction agreement with observations of Italian and perennial ryegrass yields was either good (rotations D and Dd), fair or poor (other rotations) (results not shown). STICS prediction of the N content in silage maize and harvested grass was respectively good and from fair to poor (results not shown).

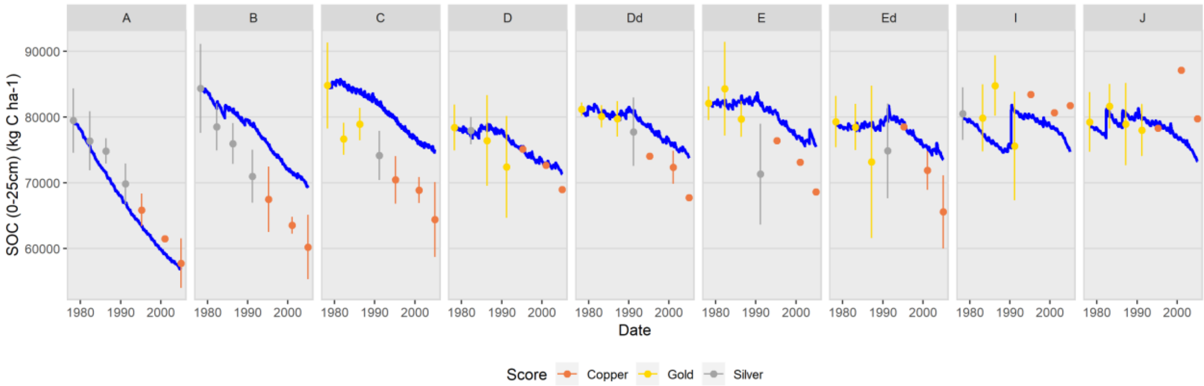

Figure 1. Comparison of simulated (blue lines) and observed (points) SOC dynamics over 27 years at Kerbernez site for nine crop-grassland rotations.

Table 1. Evaluation statistics (root mean square error (RMSE), relative RMSE (RRMSE), part of systematic error (pRMSEs), Nash-Sutcliffe model efficiency (EF) and Willmott index (d)) of STICS performance of predicted SOC

Rotation	RMSE (kg C ha^{-1})	RRMSE (%)	pRMSEs	EF	d
A	2147	3.2%	0.75	0.92	0.98
B	6598	8.5%	0.94	-0.69	0.79
C	7423	9.2%	0.89	-2.82	0.65
D	2076	2.7%	0.30	0.36	0.87
Dd	3255	4.1%	0.85	-0.64	0.81
E	5401	6.7%	0.50	-3.16	0.63
Ed	4286	5.5%	0.69	-3.04	0.68
I	5074	6.5%	0.79	-4.56	0.25
J	4783	6.1%	0.65	-2.80	0.18

Conclusions and perspectives

Further investigations are required to confirm these first results. STICS ability to simulate SOC dynamics in crop-grassland rotations will be assessed against data from two other long-term experimental sites of the INRA SOERE ACBB. If required, a calibration of the sensitive grassland root and shoot parameters will be done to improve the model prediction of SOC together with other soil and plant variables. Scoring each simulation unit will help selecting data to be used for model calibration and evaluation. The performances of STICS will also be compared with those of four other models.

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Simulation of switchgrass biomass production in Eastern Canada with the STICS model

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Keywords : switchgrass, biomass, marginal lands, Canada

Introduction

Switchgrass (*Panicum virgatum L.*) is a herbaceous perennial grass that is native to the semiarid prairies of central North America. In Canada, switchgrass is at the northern limit of its range. Cold winter temperatures in combination with a short growing season are not favourable for the northward expansion of this crop (Delaquis 2013). In these conditions, the establishment of this crop remains a challenge because it competes very poorly against weeds and takes at least 2 years to reach its full potential. Once well established, switchgrass can produce a large amount of biomass (10 t DM ha^{-1}) and remain productive for more than 10 years (Martel and Perron 2008) under Eastern Canadian agro-climatic conditions. However, according to Delaquis (2013), it is planted on only 1500 ha of cropland in Eastern Canada, mostly in Ontario and Quebec. In order to expand this area without competing with other crops its plantation on marginal lands with low soil quality is being considered.

The objective of this study is to evaluate the yield potential of switchgrass in southern Quebec using the STICS crop model. First, the model performance in predicting above-ground biomass was evaluated using field data and then, the model was used to evaluate the yield potential of switchgrass on low quality soils (low thickness, low organic matter content and/or high stone content).

Material and Methods

Three data sets were collected near Sherbrooke in Southern Quebec, Canada (45° 24' N, 71° 54' W). The same cultivar (Cave-In-Rock) was used for the three experiments (table 1).

Table 1. Experimental setup used to evaluate the model performance.

Experiment	Year of plantation	Years of measurements	Soil type	Soil organic matter content (%)	Number of measurements	
					Above-ground biomass	Leaf area index
1	2009	2015, 2016, 2017, 2018	Loam	3.8	18	18
2	2009	2018	Silty Loam	4.8	4	4
3	2017	2018	Silty Loam	4.8	4	4

In all experiments 60 kg ha^{-1} of mineral nitrogen (N) were applied in spring before the beginning of plant growth. Weather data (temperature, precipitation, solar radiation, wind speed and air moisture) were collected by a weather station close to the experimental sites (< 5km). Soil properties were estimated using the Canadian soil database. STICS was run continuously from the year of plantation to 2018. The crop growth parameters defined by Drochon *et al.* (2017) were used to run a research version of STICS (including new formalisms to simulate perennial crops). Only one parameter (*durvief = 150*) was calibrated by minimizing the difference between predicted and measured Leaf Area Index (LAI) of experiment 1 in 2015. The normalized root mean square error (NRMSE), normalized mean error (NME) and model efficiency (EF) were used to evaluate the model performance.

After the model performance evaluation, four sets of simulations were run with altered soil properties. The soil properties of experiments 1 and 2 were altered as follow: a) reduced soil depth (0.5 m instead of 1 m), b) reduced soil organic matter (OM) content (1.9 and 2.4 % instead of 3.8 and 4.8 % for soils 1 and 2 respectively), c) high stone content (15% instead of 0%), and d) combination of these three factors. Simulations for these altered soils were run using the same crop management and climate data (2009-2018) as those used to evaluate model performance. Variations in annual yield predictions were calculated by comparing the yields of these simulations with altered soil properties to the yield of the reference simulation with actual soil properties measured in experiments 1 and 2.

Results

Overall the STICS model performance in simulating the above-ground biomass (AGB) and LAI of switchgrass in Southern Quebec was good with NRMSE of 25 and 21% and EF of 0.65 and 0.87 for ABG and LAI respectively. Bias was also small with NME of +11 and -8% for AGB and LAI respectively. Model predictions tend to slightly overestimate biomass during spring and summer, but the harvested biomass in fall (11.6 t DM ha^{-1} on average) was generally very well predicted with a NRMSE of 13% and a NME of 5%. These good performances allow us to run the simulations with altered soil properties.

The largest simulated yield decrease (-12% on average) occurred when the soil depth was reduced by half. The decrease of soil OM content and increase of stone content had less impact on average yield with reductions of 8 and 4% respectively. As expected, the combination of these three factors (reduced soil depth and OM content and increased stone content) had more impact on average yield with a decrease of 26%. This yield decrease with altered soil properties was also generally associated with greater inter-annual yield variability. Despite these yield reductions, the average annual yield of switchgrass remained close to the average yield reported in this region (10 t DM ha^{-1}) with average annual yield ranging from 9.1 to 11.2 t DM ha^{-1} when one soil property is altered and close to 8.6 t DM ha^{-1} when the three factors are combined.

These simulation results suggest that switchgrass production on marginal lands with poor soil quality in Southern Quebec is possible without decreasing too largely the yield potential. Experimental data of switchgrass cropped on marginal lands are currently being collected and will be used to verify the model performance in predicting potential yield under these conditions.

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Modelling the impact of soil and climatic variability on sugarcane growth response to mineral and organic fertilisers

Impact of corn root growth parameters on soil moisture, evapotranspiration and crop growth in STICS model

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Keywords : *Zea mays* L., eastern Canada, LAI, biomass, rainfall shortage

Introduction

Most of the grain corn production (*Zea mays* L.) in Canada is located in the Mixedwood Plains ecozone, extending between Windsor (ON) and Quebec city (QC). The STICS crop model (Brisson *et al.*, 1998) was adapted for corn grown in eastern Canada (Jégo *et al.,* 2011) and its performance using earth observation (EO) derived leaf area index (LAI) assimilated to reinitialize management practices and soil moisture at field capacity was evaluated over a small region (Jégo *et al.,* 2015). STICS was also used to refine nitrogen application rate recommendations over the ecozone (Mesbah *et al.,*2017). Previous studies (e.g., Jégo et al., 2017) showed that accurate simulation of water balance, in particular soil moisture and evapotranspiration, was critical for accurate simulation of environmental outputs in eastern Canada. Our project aims at improving soil moisture initialization for the regional use of STICS using EO derived descriptors. The first step consists in revisiting the adjustment of root and soil parameters to improve soil moisture profile and evapotranspiration predictions during water stress periods and explore how to handle the extreme precipitation anomalies during the growing season, as was observed in 2017.

Methodology

Soil moisture profiles were measured using time domain reflectometry, evapotranspiration (ET) measured using an eddy covariance flux tower, and destructive sampling of LAI and shoot biomass of a corn crop planted in a 27-ha experimental field near Ottawa, Canada(45° 18' N, 75° 45' W) were acquired over two years with contrasting weather conditions in 2017 and 2018. The growing season of 2017 was exceptionally wet with 1223 mm cumulative precipitation and 2802 Crop Heat Units (CHU) from April to November. Whereas an intense drought period occurred in 2018 during a critical corn development stage with only 783 mm cumulative precipitation and 2133 CHU from April to November. Actual management practices of the experimental field were implemented in the simulations of both years. Corn was planted on 30 May 2017 and on 14 May 2018 at a plant density of 8 plants m^{-2}. Soil moisture at field capacity and wilting point were derived from pedotransfer functions (Saxton *et al.,* 1986) using soil texture. Soil organic N content was set at 0.15% and the cumulative soil evaporation above which evaporation rate is decreased, *q0*, was set at 3 mm. We used the corn cultivar adapted for the northern part of the ecozone (Jégo *et al.,* 2011). Since a large proportion of fields in eastern Canada, including this experimental field, are tile drained and because previous studies showed that soil moisture rarely exceeds field capacity, the macroporosity was not activated in these simulations. Fig.1 summarizes the impact of parameter adjustments in the STICS model for 2018.

Results and discussion

Predicted and measured ET in the 2018 growing season (Fig.1a) were in good agreement, except over the drought period. This issue was observed in past growing seasons when water shortages occurred (data not shown). Evaporation was well predicted after the crop harvest; however, in the spring, predictions were overestimated. Soil moisture was relatively well predicted for the different soil layers in 2018 (Figure 1c). However, from late July until harvest, the dry-down estimates of the upper top soil layers were too close to field capacity following rainfalls. The default parameter values tended to overestimate the LAI and biomass predictions in 2018 (Fig.1e and 1f). To ameliorate this, some root growth parameters were adjusted: *i)* decrease the maximum rate of root length production per plant to better simulate the impact of water stress on the crop development in 2018 and *ii)* increase root density in upper soil layers compared to subsoil root density to better simulate soil drying periods. The overall results of predicted ET in 2018 were improved and RMSE decreased from 1.04 to 0.83, while the overestimation of spring evaporation remained (Fig.1b). The new set of parameter values allowed the model to better predict the soil moisture dry-down following a rainfall. The moisture in the upper soil layers remained close to field capacity (Fig.1d). Predicted LAI were improved in 2018 (Fig.1e) with RMSE decreasing from 0.84 to 0.50. As the predicted biomass is closely related to the LAI, the shoot dry biomass prediction over time (Fig.1f) showed a better fit, although the maximum biomass predicted was still overestimated. Using the new set of parameter values in 2017 increased the discrepancies between measured and predicted soil moisture (results not shown) compared to the default values. The observed soil moisture was close to saturation due to the frequent rainfalls. This trend could not be predicted by the model since soil macroporosity was deactivated. Therefore, activating the macroporosity should be considered during exceptionally wet seasons to account for soil moisture above field capacity.

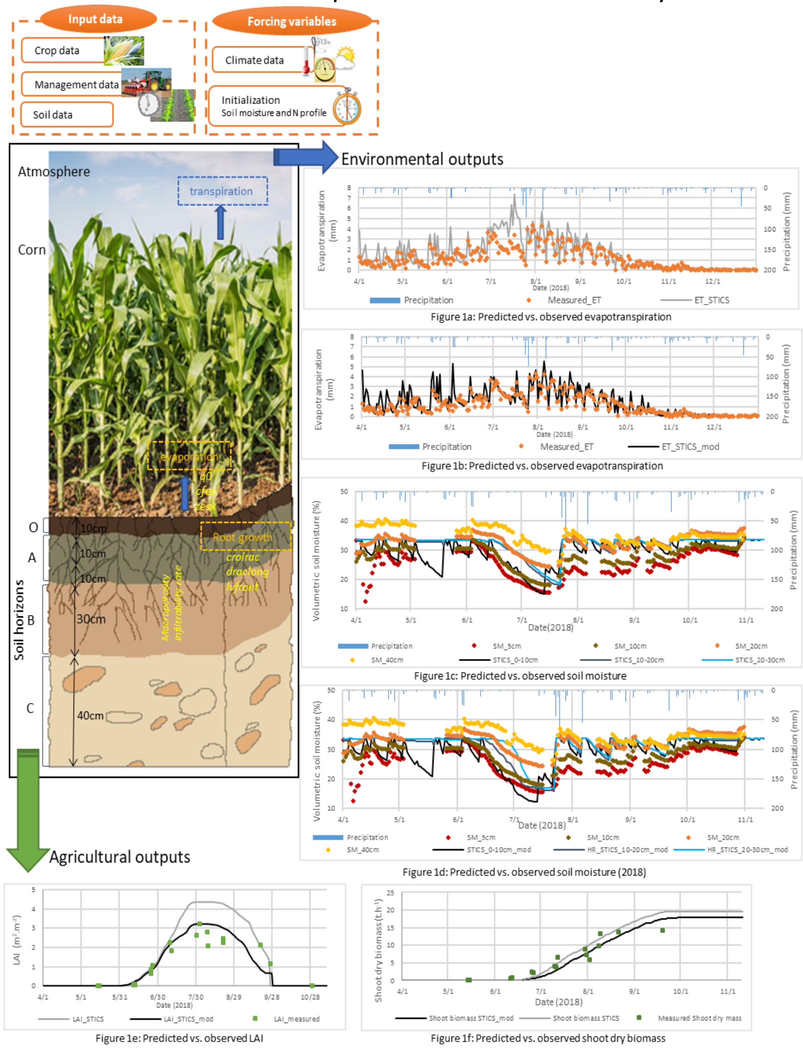

Fig 1. Impact of STICS parameters adjustment on a&b) evapotranspiration, c&d) soil moisture e) LAI and f) shoot biomass in 2018 growing season

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Impacts of observed and projected climatic constraints on rainfed wheat yield under a typical Mediterranean condition

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Introduction

Under Mediterranean climates, rainfed wheat grain yield is often constrained by late season occurrence of enhanced water deficits and high temperature events that is primarily overlapped with the anthesis and grain filling periods (Asseng et al., 2011; Moriondo et al., 2011). This vulnerable aspect is expected to be exacerbated with projected warming and drying trend for Mediterranean basin (Mariotti et al., 2015). Our aims are to evaluate the yield impacts of these climatic constraints in the past in a typical Mediterranean region and their likely variations under projected climates, as well as how adaptations could help mitigate these impacts.

Materials and Methods

The study was performed for the Alentejo region in southern Portugal over baseline (1986–2015), future short- (2021–2050) and long-term (2051–2080) periods. STICS model was chosen to simulate wheat crop growth and yield formation, which was successfully calibrated using 5-year field data at one representative site (Beja). The model was further operated at regional scale by coupling with high-resolution climate and soil datasets and running with common practices at a harmonized resolution (~12.5 km). Calibrated STICS proved to be able to well reproduce baseline regional yield statistics and measured potential yields at experiment stations. In future periods, simulations were only conducted at Beja, where climate projections under RCP4.5 and RCP8.5 were retrieved from 10-member bias-adjusted regional climate model ensemble from EURO-CORDEX (Jacob et al., 2014). Tested adaptation options are sowing date adjustment, using early-flowering cultivars and supplemental irrigation during sensitive period.

Results and Discussion

As an illustrative example, the mean climatic water deficit and high-temperature events during three wheat growing periods over baseline are shown at Beja, which are clearly more pronounced in the last phase (April-June) (**Fig. 1a**). In baseline, terminal water stress appears to be the main limiting factor for the potentially attainable yield, causing 40–70% yield gaps between actual and potential yield across the region. In future periods, projected enhancement of water deficits and more frequent hot days in April–June (**Fig. 1b**), are likely to considerably reduce actual yields (**Fig. 1c**). Early flowering cultivars help advance the anthesis onset and grain filling, which reduce the risks of exposure to the terminal drought & heat stresses, whereas early sowing benefits can be inhibited with slowed vernalization fulfilment (Yang et al., 2019).

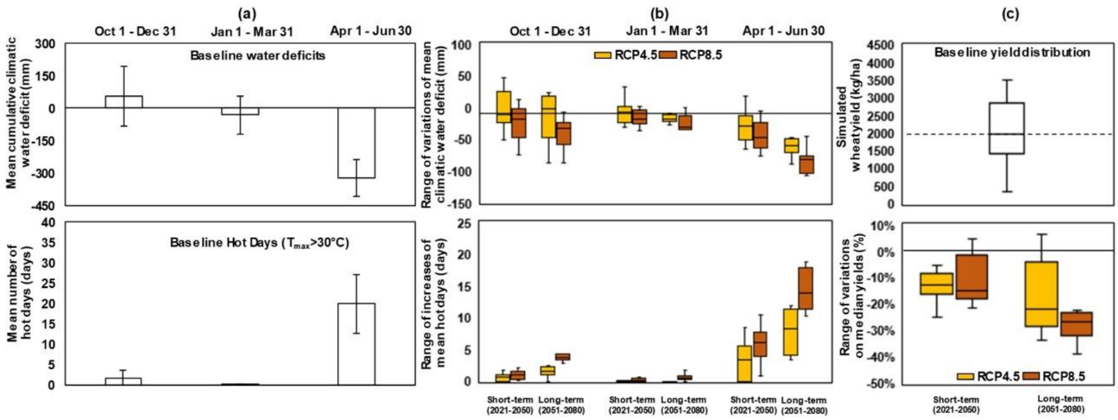

Figure 1. An illustrative example of observed and projected climatic constraints during wheat growing season at one representative site (Beja) of Alentejo region in southern Portugal. (**a**) Mean and standard deviation (error bar) of cumulative climatic water deficit (precipitation minus potential evapotranspiration, mm) and of hot days (daily maximum temperature above 30°C) during three wheat growing periods over baseline, along with their (**b**) projected range of mean changes during short- (2021–2050) and long-term (2051–2080) future periods under RCP4.5 and 8.5 among 10 bias-adjusted regional climate model projections. (**c**) Projected likely range of variations (%) during 2021–2050 and 2051–2080 relative to the simulated median baseline (1986–2015) yield.

Conclusions

The detrimental effects of climatic water deficits and hot days occurring during wheat grain filling can represent the major cause of gaps between actual and potential yield in Alentejo region, which are likely to be widened under future climate. Combination of using early-flowering cultivars with no or less vernalization requirement and supplemental irrigation can help reduce the yield gaps, being a promising adaptation strategy for rainfed wheat cropping system under Mediterranean climate.

Acknowledgments

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Session 6: Regional and large scale simulations using STICS

Estimate demand for irrigation water and nitrogen fertilizers in Europe at different scales

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Keywords : yield function, irrigation water, nitrogen fertilizers, climate change, agro-economic model, European Union

Introduction

The demand for prospective analysis of agricultural activities and their impacts in terms of environmental externalities brings to light the need for quantitative models enabling them to be evaluated in contexts that have not yet been observed. Estimating what the environmental impacts of demand for inputs could be in a context of global change affecting this same demand is the example of the analysis of feedbacks that we are called upon to process. An illustration of the problem is given by the effects of climate change on agriculture and the greenhouse gas emissions to which it contributes and which play a large part in climate change. In addition to climate change, there is also the economic regulation of nitrogen pollution which could affect agricultural activity just as significantly. Finally, the modification of the precipitation regime and the economic pressure on the water available for irrigation are likely to affect even more an agricultural system at the heart of complex relationships with its environment. We propose to show our contribution in the modeling of these processes from an economic perspective.

The key data problem and the choice of models

More often than with regard to physical data, the elements available in economic databases are insufficiently present for the study of environmental impacts in relation to agricultural activities. This is particularly the case for consumed inputs which escape the market, for example with regard to part of the irrigation water. This is also the case for nitrogen fertilizers for which we observe the consumption in value of synthetic fertilizers, but whose distribution by crop or chemical composition is poorly known. The observation is both biased by the lack of information on quantities and even more so on prices. Another major obstacle is the difficulty of accessing data when it exists, as is the case with the Farm Accounting Information Network (FADN). The use of bioeconomic models helps to overcome this problem.

The coupling of an economic model of agricultural supply with a crop model (in this case AROPAj and STICS respectively) makes it possible to deal with the problem of the choice of activities at the decisional level which is that of the agricultural holding, while the crop model allows the economic model to deal more realistically and in the absence of economic data, the problem of decision at the plot scale. The heart of the association of models is based on the selection of crop yield functions. The method initiated for the nitrogen input by Godard et al, 2008, and completed by Leclerc et al, 2013, has been extended to irrigation water by Humblot et al., 2017. It has been refined in the context of a study carried out on behalf of the JRC-Seville in 2019. Finally, combined with a spatial econometric model, the AROPAj-STICS coupling makes it possible to assess the spatial distribution of agricultural production, consumption of inputs and pollution associated (Jayet et al., 2018).

Spatial distribution of input demand

The STICS model is used to produce yield functions for 9 crops (durum wheat, soft wheat, barley, corn, rapeseed, sunflower, soybean, potato, sugar beet) and for all farms representative of the 130 regions of the European Union and represented in AROPAj. The economic data are the yields and prices estimated from the European FADN (2008-2012).

A first simulation carried out for 2012 with AROPAj is used to illustrate the demand for "filtered" irrigation water by estimating a variable irrigation load from the FADN (fig. 1). A second simulation is carried out without "filtering" the water demand, so that one can estimate what would be a demand for irrigation water if the irrigation system existed (fig 2.). The color scheme used in the two figures corresponds to different value ranges (m3 / ha). It should be emphasized that these estimates relate to "hectares of UAA AROPAj", given that the model represents part of the total agricultural UAA.

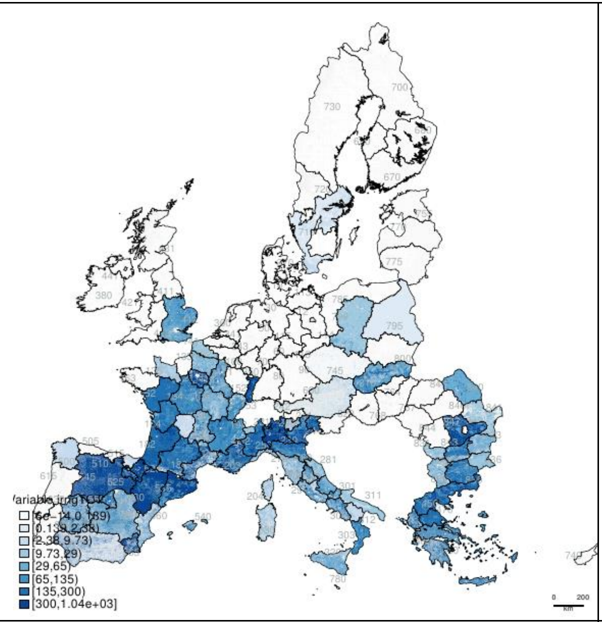

Fig. 1. Demand for irrigation on FADN-2012 basis

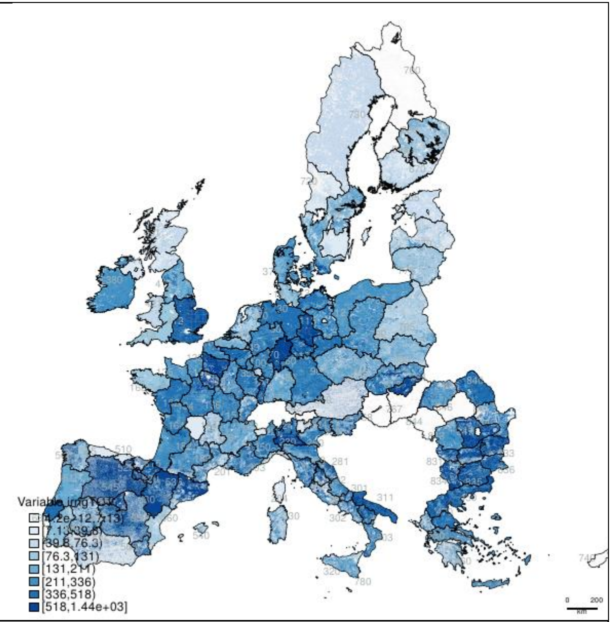

Fig. 2. Demand for potential irrigation (2012)

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Regional-scale coupled modelling of water pollution by nitrate from agricultural sources: the Seine-Normandy hydrosystem case study

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Keywords: coupled modelling, nitrate pollution, nitrogen leaching, foresight scenarios

Introduction

Agricultural lands represent nearly 70% of the surface area of the Seine-Normandy basin. The multiplicity and diffuse nature of the hydro-physico-chemical processes involved in the transfer of agricultural-source nitrogen (N) make the characterization of their impacts on the quality of the basin water resources a challenging and complex issue. In this context, an original interdisciplinary modelling platform has been developed (Gallois and Viennot, 2018).

Material and method

The platform deals with the main processes affecting water quality along the aquatic *continuum* by linking the STICS, MODCOU and RIVERSTRAHLER models (Ledoux *et al.*, 1984; Billen *et al.*, 1994; Brisson *et al.*, 2009).

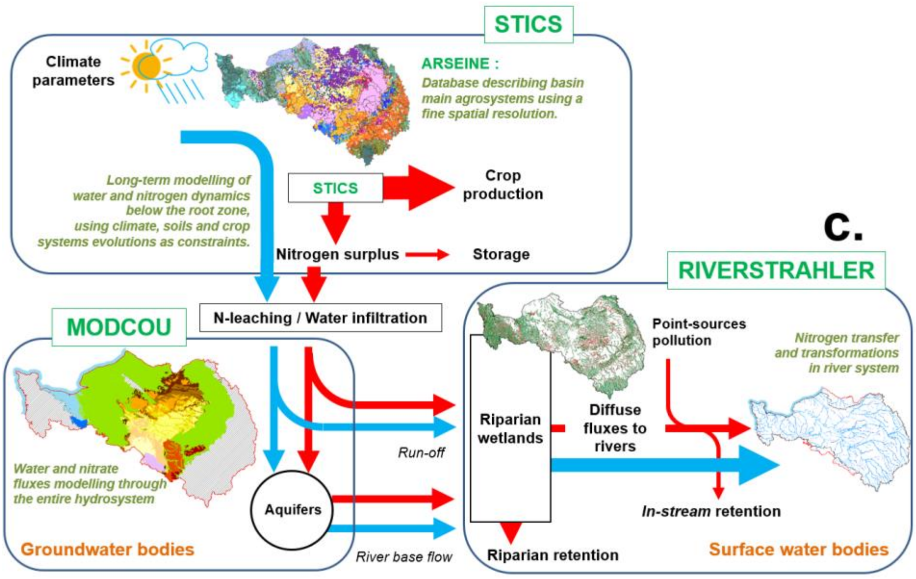

Figure 1: Diagram of the integrated modelling platform of the Seine-Normandy basin. Water flows in blue, N flows in red.

Over the simulated domain (100,000 km^2 approximately), model interactions (cf. Figure 1) are set in order to:

- Generate water and N flows below the sub-root zone using the STICS v10 code. STICS inputs resulted from the spatio-temporal evolutions of agricultural practices describing over 4,500 cropping systems since 1970 (ARSEINE v3.4.3 database, INRA Aster) (Puech *et al.*, 2018) as well as climate data

(SAFRAN, Météo-France) and soils characteristics (BDGSF, INRA InfoSol). A dedicated software allowed their integration and the STICS distribution over the territory (Gallois and Viennot, 2018);

- Synchronously model nitrate and water flows transiting through sub-surface, unsaturated and saturated compartments of the regional hydrosystem, using the MODCOU hydrogeological model;
- Model N transfer and transformations across the 36 000 km-long river system *via* the RIVERSTRAHLER model, computing geographical distributions of N-concentrations in the network.

Results and implementation

The platform's ability to reproduce the agro-hydrosystem behavior was assessed at three levels:

- *Indirect validation of STICS water drainage and N-leaching flows* : The development of a *Quality Assurance Protocol* (QAP) (Beaudoin *et al.*, 2018) combining sensitivity analysis and agronomic expertise of STICS inputs and outputs allowed to evaluate the reliability and consistency of STICS simulations at the macro-regional scale;
- *Direct validation on nitrate concentration rates in aquifer system*: The aquiferous nitrate content was predicted with a maximum absolute bias less than 10 mgNO_3 L^{-1} at 580 control points (cf. Figure 2);
- *Direct validation of nitrogen supply dynamics in the river system*: Simulated river concentrations were compared with available observations at the gauging station scale (cf. Figures 2a, 2b, 2c).

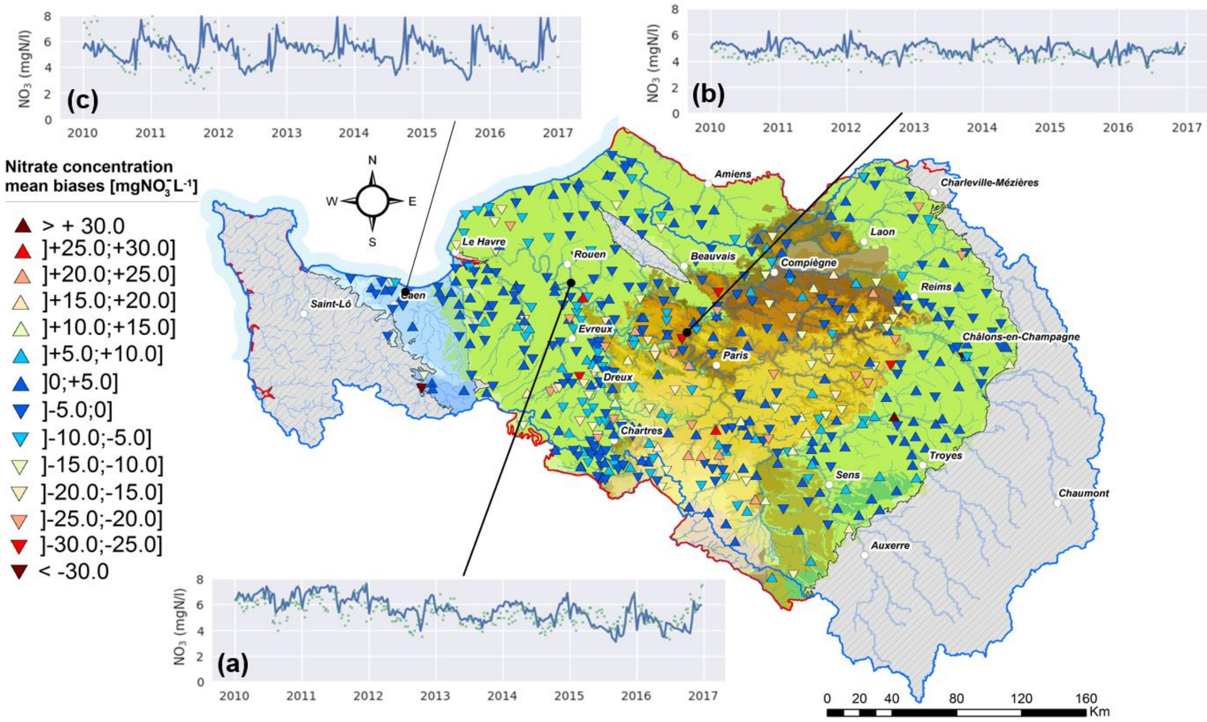

Figure 2. Average biases (1995-2016) between simulated aquiferous nitrate concentrations and measured data at the scale of instrumented boreholes. Three examples of synchronous time evolutions between observed and simulated concentrations in rivers (2010-2016; mgN-NO3 L^{-1}) at stations located at the (a) Seine, (b) Oise and (c) Orne river outlets are also displayed.

Relying on these performances, the platform allowed a complete assessment of N-related transfer and transformation processes along the soil-hydrosystem *continuum* over 50 years (Passy et al., 2018). It also permitted to study the sensitivity of groundwater to two contrasting foresight agriculture scenarios over 2017-2050 period (conventional and agro-ecological - Puech et al., 2018).

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Simulating innovative cropping systems aiming at producing biomass while reducing greenhouse gas emissions in the Hauts-de-France region

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Keywords: cropping systems, biomass production, evaluation, GHG balance

Introduction

Biorefineries, which use renewable biological resources for the production of bio-based products and biofuels, are a cornerstone of the bioeconomy. However, creating a biorefinery in a territory requires increasing local biomass production, without affecting too much food production and with limited environmental impacts. It raises the need for developing innovating cropping systems able to fulfill these criteria. We aimed at evaluating *ex ante* these cropping systems using the STICS model.

Material and methods

The geographical context of this work was the Hauts-de-France region and more precisely the area (50 km radius) around Venette (Oise). We focused on two soil types: a deep loamy (DL) soil representing the most widely spread soil type in the study area and a sandy loam (SL) representing soil types with lower potential agricultural production. Soil characteristics were obtained using local references.
First, reference cropping systems representative of the region were defined using agricultural surveys and local expert knowledge: 6 for DL and 5 for SL. These cropping systems were two to five year annual crop rotations including grain cereals (wheat, barley, maize), sugar beet, rapeseed, spring pea, potato and mustard as a catch crop (CC). In a second step, innovative cropping systems were designed during dedicated workshops involving researchers and local experts. The following target was assigned to these cropping systems: reducing greenhouse gases (GHG) emissions by 50%, increasing total biomass production by 5% and decreasing food production by no more than 20%. One cropping system was designed for the deep loamy soil combining two cropping systems within a same plot: (1) a ten-year crop rotation with alfalfa (3 years) – rapeseed – CC/winter wheat – CC/sugar beet – winter wheat – CC/potato – spring pea – CC/winter wheat; (2) a miscanthus-based system (27 years of miscanthus with winter wheat as preceding and following crop), grown as six-meter wide strips inserted into the first system every 24 meters. One cropping system was also designed for the sandy loam: a height-year crop rotation with switchgrass (4 years) – winter wheat – CC/sugar beet – spring pea – CC/winter wheat.
Then, production and environmental impacts of reference and innovative cropping systems were simulated with the STICS model. We used a research version of the STICS model able to simulate rotations including perennial crops (Autret, *et al.* 2019). Simulations lasted 30 years and were repeated with three different climatic series (all using randomly sampled years from the period 1984-2016).
Finally, STICS outputs were analyzed to evaluate their reliability (using local expert knowledge and experimental references) and to compare reference and innovative cropping systems. A partial GHG balance (including N fertilizer synthesis, direct and indirect N_2O emissions and changes in soil organic carbon (SOC) stocks) was calculated according to Autret *et al.* (2019).

Results and discussion

Regarding reference cropping systems, mean simulated yields per crop and soil type were well correlated with yields obtained from local experts (R^2 = 0.84) but generally slightly overestimated (+0.4

t DM ha^{-1}, *i.e.* +10% on average). Simulated mean biomass and nitrogen harvest index for each crop (Figure 1) were very close to experimental references in similar conditions (*e. g.* Beaudoin *et al.*, 2008), as well as nitrogen concentration in harvested products and crop residues (data not shown).

Figure 1: Comparison between mean simulated harvest index per crop and experimental references

According to STICS simulations, innovative cropping systems were able to maintain high levels of production (close to the most productive reference), with a much lower N fertilization (Table 1). However, direct N_2O emissions were similar to emissions in the reference cropping systems, probably because lower N fertilization was partly compensated by higher inputs through biological N fixation. SOC stocks decline was higher with innovative than with reference cropping systems, but the uncertainty for this result is probably high (simulation of SOC stocks under perennial crops needs further evaluation). As a result, innovative cropping systems had, as expected, a lower GHG balance than the reference, but did not reached the initial target of 50% reduction.

Table 1: Simulated production and environmental performances of reference and innovative cropping systems

Soil	Cropping system	Production (t DM ha^{-1} yr^{-1})	N fertilization (kg N ha^{-1} yr^{-1})	N_2O emissions (kg N ha^{-1} yr^{-1})	SOC storage (kg C ha^{-1} yr^{-1})	GHG Balance (kg CO_2eq ha^{-1} yr^{-1})	
						Without SOC	With SOC
DL	Reference [min - max]	[9.6 - 12.1]	[140 - 187]	[1 - 1.2]	[-100 - -15]	[1412 - 1824]	[1700 - 2191]
	Innovative 1+2	11.7	88	1.1	-119	1088	1522
LS	Reference [min - max]	[5.1 - 7.7]	[146 - 169]	[0.4 - 0.4]	[-95 - 26]	[1219 - 1392]	[1288 - 1742]
	innovative	6.7	70	0.4	-138	737	1243

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New crop fertilization strategies after introduction of anaerobic digesters in a territory and their consequences on carbon and nitrogen dynamics in soils: case study of the Versailles plain.

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Keywords : digestate, carbon storage, nitrogen emissions, cover crops

In addition to energy production, the development of anaerobic digestion in a territory can have many indirect effects. The characteristics of the exogenous organic matters (EOM) spread on soils are changed after anaerobic digestion (Möller & Müller, 2012). More generally, the development of anaerobic digestion may affect the supply of available EOMs and even the cropping systems: mobilisation of crop residues that only return to the soil after digestion, modification of crop successions to introduce cover crops for energy supply (CCESs) in substitution for catch crops, etc. Depending on the chosen anaerobic digestion scenarios, these indirect effects will lead to changes in the carbon storage and nitrogen dynamics (Askri, 2015; Nicholson et al., 2017)

The objectives of the study were to simulate the consequences of anaerobic digestion development on carbon (C) and nitrogen (N) flows at the plot scale. The case study was the Versailles plain, a territory with very little livestock and mainly field crops. This territory has been previously characterized: soil types, crop successions, EOM used, climate. The considered initial soil organic carbon content was low (no past application of EOM considered).

The consequences of anaerobic digestion development on C and N flows at the plot scale were simulated with the STICS crop model (Brisson et al., 2009) with a focus on: (i) organic C stocks in soils, (ii) N uptake by plants, (iii) leached N fluxes, (iv) N fluxes volatilized as NH_3 or emitted as N_2O. The STICS model was coupled with a model for predicting the characteristics of digestates developed as part of the MethaPolSol project (Bareha, 2018). Thus, the characteristics of the digestate spread were produced from a mixture of animal manures and CCESs. In addition, the decomposition submodule for exogenous organic matter in STICS has been modified by subdividing the organic residue, initially only describe with one decomposable pool (Nicolardot et al., 2001) into two fractions, a fast decomposable fraction and a slow decomposable fraction that is directly incorporated into soil humus (Levavasseur et al., subm.).

Four series of simulations were carried out: (1) crop successions with mineral fertilization, (2) crop successions with the EOMs actually used, (3) crop successions with substitution of fertilizers by digestates of bio-waste or livestock effluents, (4) crop successions with implantation of CCESs where possible and substitution of fertilizers by digestates mixing livestock effluents and CCESs. The scenarios were simulated over 30 years with the following criteria: limitation to 170 kg N/ha provided with EOMs per crop, mineral N supplementation to achieve constant yields and decrease in the mineral N dose as soil nitrogen supply increases with the increase of organic matter stocks in soils. All scenarios were constructed to simulate yields similar to those obtained with mineral fertilizers.

The simulation results showed that soil C stocks were stable for successions receiving only mineral fertilizers (scenario 1), they increased in all scenarios receiving EOMs (current or digested, scenarios 2 to 4) with intensities depending on the humic potential of EOMs used and the quantities supplied. The introduction of CCESs in the digestate scenario (4) increased C storage thanks to a higher return of root and digestate C. EOM use increased the substitution of mineral fertilizers over time, due to the mineral N contents of EOMs, particularly in the digestates, and the increase in organic matter stocks in soils that generated increasing mineralized N flows. The CCESs tended to reduce these savings. Because of this increasing mineralized N flows and the limited N uptake in summer and autumn in the simulated crop successions (especially with wheat), N losses from leaching and N_2O emissions increased over time in all scenarios receiving EOMs (2 to 4). By acting as catch crops, CCESs significantly reduced N leaching (scenario 4). Ammonia volatilization was one of the main causes of N losses from crop systems fertilized with digestates (up to 20% of ammonia N input, scenarios 3 and 4).

A plot-based greenhouse gas balance including C storage, direct and indirect N_2O emissions and emissions from fertilizer manufacturing completed this work.

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Session 7: Scenario simulations using STICS

To maximize multiple ecosystem services without dis-service for water, the management of cover crops has to be climate and soil specific. A simulation approach using STICS model.

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Keywords: STICS model, simulation study, cover crop management, next cash crop, water, nitrogen

Introduction

Cover crops provide multiple ecosystem services such as reducing nitrate leaching, producing “green manure” effect, improving soil physical properties, increasing carbon storage in the soil and controlling pests, diseases and weeds (Justes et al., 2017). Cover crops increase evapotranspiration by increasing cover transpiration and decrease soil evaporation, and then they reduce water drainage in temperate climates (Meyer et al., 2019). However, the equilibrium of these processes and ecosystem services provided depends on cover crop management, climate and soil type. No consensus exists on the impact of cover crops on soil water availability for the next cash crop. Dynamic soil-crop models can be a powerful tool to estimate water fluxes that are difficult to measure in field experiments, such as drainage, evaporation, and transpiration. They can also be used over long climatic series for evaluating their variability versus weather and a wide range of management practices (Bergez et al. 2010). We hypothesis that the cover crop management must take into account soil and climate context to maximize the multiple ecosystem services and in the same time reduce the negative impact of cover crops on soil water balance and on the next cash crop. Our goal was to analyse by simulation the best cover crop managements according to soils and climates in the Adour-Garonne catchment.

Materials and Methods

We performed a multi-simulations approach with the STICS soil-crop model (Brisson et al., 2003). The soil and climate diversity of Adour-Garonne catchment (southwestern France) was represented by an east west transect using five specific locations. We tested one bare soil management as control and three different cover crop species with several management: sowing (four dates), termination (four dates), residues management (2 types). We then tested two following cash crops for evaluating the following effect on sunflower (rainfed) and maize (irrigated). The STICS model cover crop parameters were calibrated by Constantin et al. (2015) for Italian rye grass and white mustard, Tribouillois et al. (2016) for vetch, and Meyer et al. (2020) for Ethiopian mustard-crimson clover bispecific mixture.

Results and discussion

Our simulation results confirm that cover crops already reduce water drainage and increase actual evapotranspiration in comparison to bare soil. They also decrease nitrate leaching and for some cases (non leguminous species and late termination date) reduce soil nitrogen availability for the next cash crops. However, cover crops would never induce a water or nitrogen stress of the succeeding cash crop, likely to lead to lower yields, in case of early termination (at least one month before sowing). In some cases, simulated water and nitrogen stress were simulated in particular with a termination cover crop the day before the cash crop sowing and for year where no drainage would occur due to very low winter and spring rainfalls.

Moreover, our study presents the interactions between various cover crop managements, climate and soil contexts, cover crops species, and dates of sowing or termination. The use of legumes as sole cover crop or in mixture with crucifer can even increase yields, but their use must be reasoned in relation to the issue of nitrate leaching in areas with high drainage level. The figure illustrate for one site (at

Toulouse-Auzeville) the results obtained by crossing all factors. This indicate the importance of optimising together the type of species used and the dates of sowing and termination, for providing a high level of compromise in ecosystemic services.

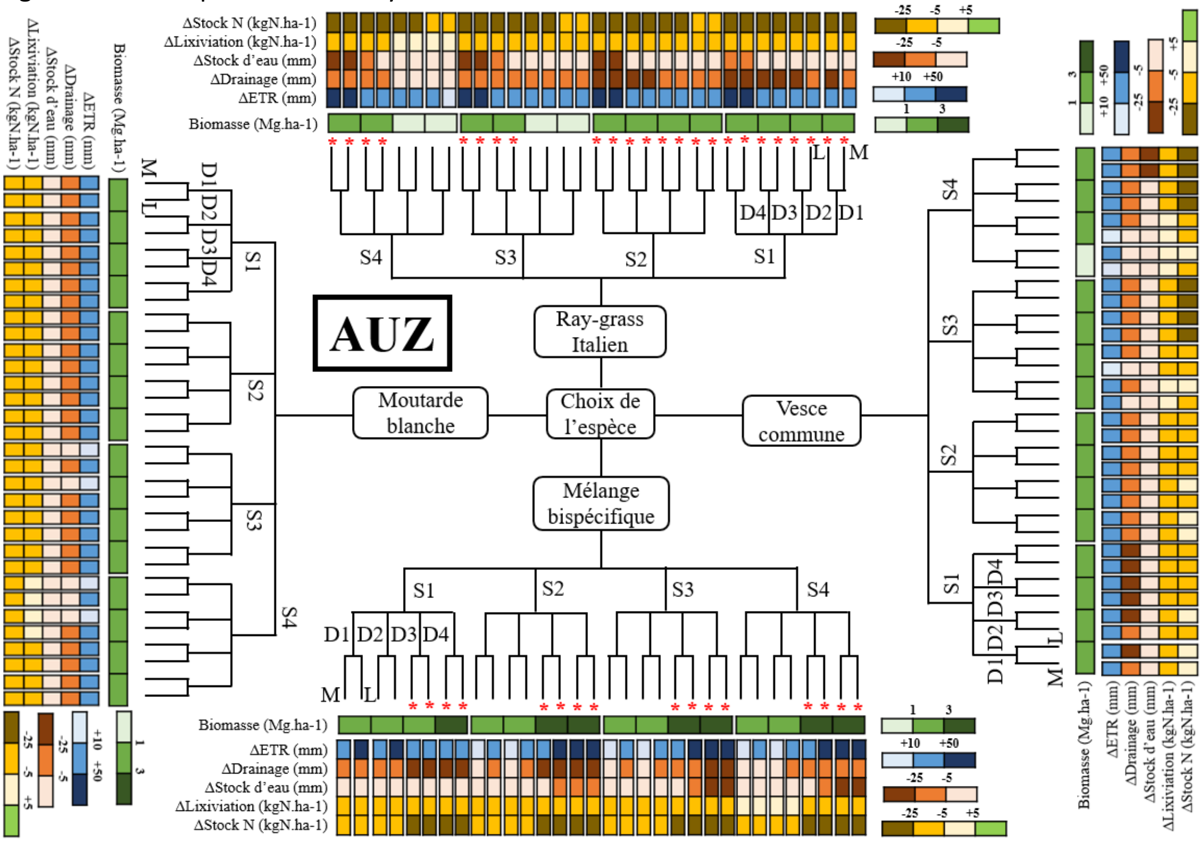

Figure 4.5. Bilan des différents itinéraires techniques des CIMS en comparaison avec un sol nu sur le site AUZ. Les variables d'intérêts sont la biomasse des CIMS à la destruction, les différences d'ETR, de drainage et de lixiviation durant l'interculture, et les stocks d'eau et d'azote au semis de la culture principale suivante. S représente les dates de semis (S1 = 5 août, S2 = 20 août, S3 = 5 septembre, S4 = 20 septembre). D représente les dates de destruction (D1 = 15 novembre, D2 = 15 décembre, D3 = 15 mars, D4 = 15 avril). Les lettres M et L représentent respectivement des résidus laissés en mulch après destruction et des résidus enfouis par un travail du sol. Les étoiles rouges et vertes indiquent les gestions de CIMS pouvant conduire à des réductions ou des hausses de rendements de la culture principale suivante

Conclusion

The impact of cover crop mixture on the water balance must therefore be investigated in new field experiments or by simulation in order to optimise the date of destruction with regard to the different services targeted by this type of plant cover, in order to propose locally optimised management rules.

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Simulating soil organic carbon dynamics in long-term bare fallow and arable experiments with STICS model

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Keywords : soil organic carbon, mineralization, carbon inputs, cropped soils, bare fallow soils

Introduction

Accurate modelling of soil organic carbon (SOC) dynamics on the long-term is required to better predict the environmental impacts of cropping systems and notably their potential to sequester atmospheric CO_2 into SOC that can play an important role in greenhouse gas mitigation and soil fertility. To date, a limited number of studies have been conducted to evaluate the ability of STICS to simulate soil organic nitrogen dynamics (*e.g.* Constantin et al. 2012; Autret et al. 2019; Yin et al. 2020). There is therefore a need to assess the ability of STICS to simulate SOC dynamics and to compare its modelling performances with models validated for various situations.

Methods

A research version of STICS (Autret et al., 2019) was used to simulate SOC dynamics (0 to 20-30 cm) in long-term field experiments that were either under bare fallow (Farina et al. 2019) or cultivated conditions (Table 1).

Table 1. Description of the selected long-term experiments.

Experiment	Code	Rotation	Duration (years)	Initial SOC stock (t C ha^{-1})	Final SOC stock (t C ha^{-1})
Askov-B3/B4	Ask3/4	Bare fallow	29	52.1/47.7	36.4/33.0
Grignon	Grign	Bare fallow	48	41.7	25.4
Kursk	Kursk	Bare fallow	36	100.3	79.4
Rothamsted	Roth	Bare fallow	49	71.7	28.6
Ultuna	Ult	Bare fallow	51	42.5	26.9
Versailles	Vers	Bare fallow	79	65.5	22.7
La Cage-Co-B1/B2	Cage-Co1/2	Pea-Wheat-Rapeseed	16	43.4/37.5	44.7/38.8
La Cage-Li-B1/B2	Cage-Li1/2	Pea-Wheat-Rapeseed	16	49.5/37.6	48.3/40.0
Feucherolles-Min	Feu-Min	Wheat-Grain Maize	15	43.4	43.3
Feucherolles-T0	Feu-T0	Wheat-Grain Maize	15	42.7	39.0
Kerbernez-A	Kerb-A	Silage Maize	26	81.7	57.8

The model performances were compared with those of the annual time-step carbon model AMG v2, which had been previously validated for various pedoclimatic conditions and cropping systems (Clivot et al. 2019).

Results and discussion

Results show that STICS could predict satisfactorily final C stocks after a long-term monitoring of SOC in bare fallow and cultivated systems (Fig. 1). The diversity of experiments suggests that STICS was able to simulate well both decomposition and mineralization derived from native soil organic matter and from fresh organic residues that are incorporated into humified organic matter.

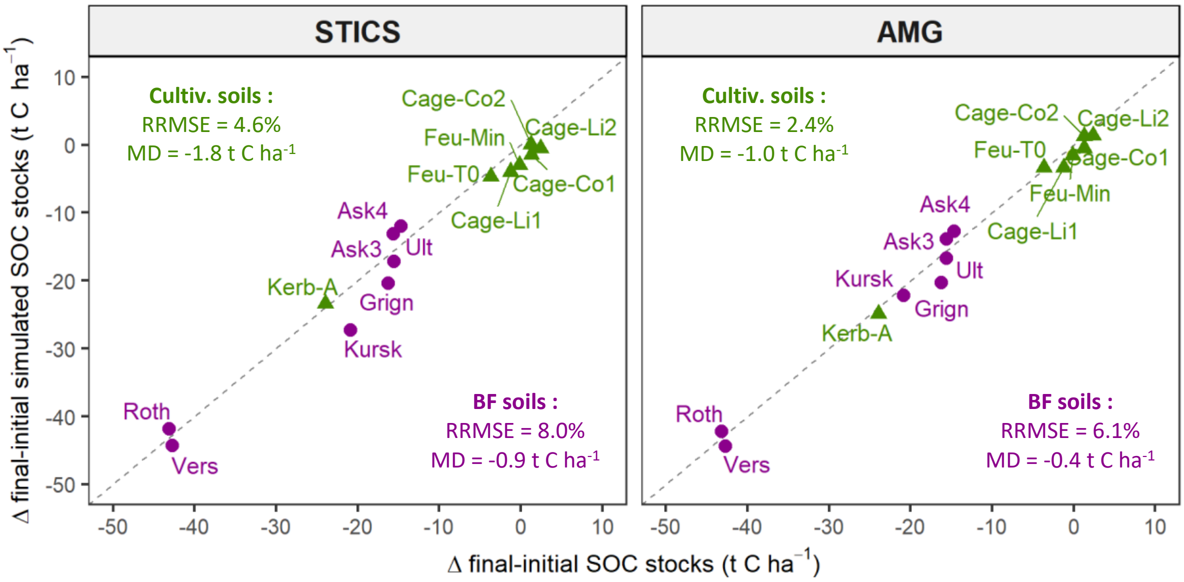

Figure 1. Differences between final and initial observed SOC stocks *vs* simulated with STICS and AMG models for bare fallow (BF) and cultivated soils in long-term experiments.
RRMSE = relative root mean square error and MD = mean difference for final SOC stocks.

The performances of STICS in simulating SOC are comparable to those of AMG model (mean RRMSE of 6.3% and 4.3% for final SOC stocks simulated with STICS and AMG, respectively), for which C inputs into soil require measured crop yields to be calculated, while STICS provides the advantage of simulating crop growth and residues returned to the soil.

Further studies will be needed to assess the model ability to simulate SOC dynamics in other systems such as grasslands or cropping systems including perennial species.

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Participative approach with STICS for evaluation of nitrogen management scenarios in organic farming systems

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Keywords: Legume, Multicriteria optimization, Participatory research, Numerical experiment

Introduction

Organic farming (OF) is considered as a prototype of sustainable agriculture. However, its environmental performances linked to carbon (C) and nitrogen (N) cycles seems perfectible (Mondelaers *et al*., 2009; Sautereau *et al*., 2016). The N factor also plays a key role in production, interacting with weeds (Casagrande *et al*., 2009). Deterministic dynamic modelling, if realistic, should help to optimize OF systems. Recently, applications of the STICS research version (v1680) in OF relied on the following hypothesis: (H1) if weeds, pests and diseases are quite well controlled, an agro-environmental model can reproduce satisfactorily aboveground biomass and water-CN budgets. The H1 hypothesis has been validated in on-farm situations on an annual scale (Beaudoin *et al*., 2018) and on long-term trials (Autret *et al*., 2019). In addition, the participative approach, well known in OF, could help to take into account biotic factors (Desclaux *et al*., 2012). The second hypothesis was combining deterministic modelling and agricultural stakeholders would be relevant to optimise OF systems (H2). The work carried out during Rakotovololona's thesis (2018) was based on a numerical experiment to test scenarios co-designed by researchers, farmers and agricultural advisors, from real situations.

Material and methods

Rakotovololona's thesis (2018) was based on a monitoring network of organic fields in Hauts-de-France (France). From a preliminary diagnosis, two themes were prioritized by the workshop: (1) the fallow cropping management after harvest of grain legume and (2) the fallow cropping management afteralfalfa ploughing. Different N management practices, eventually combined, were proposed by farmers. For each risky situation studied, three benchmarks represented by a "plot-year" couple were chosen. The same combinations of modalities were applied to each benchmark. The simulations are replicated on real climate series, with a duration of 4 to 6 years, over the period 2000 - 2017. A scenario is a combination of management modalities for a given plot, simulated with sequence over real years (called A) then the two years of interest (called B”), under a given climate series.

Results and discussion

The predictions of STICS are first tested on the data acquired in A years, in chained simulations of a duration of 2 to 3 years. The predictions of the total aboveground biomass, the amount of N in the aerial part, the soil water stock, and the soil mineral nitrogen (SMN) stock are sufficient with efficiencies of 0.93, 0.55, 0.63 and 0.64 respectively. In addition, simulations of SMN dynamics before, during and after alfalfa cropping have been successfully tested by Strullu *et al*. (2020).

Predictions for B years are then discussed with farmers. The variables of interest are at the same time agronomic (yield, dry matter, mineralized nitrogen,...) and environmental (drainage, NO_3 leaching, N_2O emissions). The SMN stock evolution appears sensitive to the fallow period management scenario, intersecting the length of the period and the type of multiservice catch crop, with the addition of climate hazards (Figure 1). Likewise, N mineralization were very sensitive to the alfalfa ploughing scenarios, according to the period of destruction and the fate of the last cut; it statistically significantly varied between 382 and 580 kg N ha^{-1} for two years (data not shown). The N losses were rather high but less sensitive to the scenarios, with NO_3 leaching being between 55-69 and N_2O emissions being between 3.2-4.5 kg N ha^{-1}, both for two years. However, the final SMN remained high and variable from 75 to 175 kg N ha^{-1}; so, it would be better to investigate these impacts over a longer period.

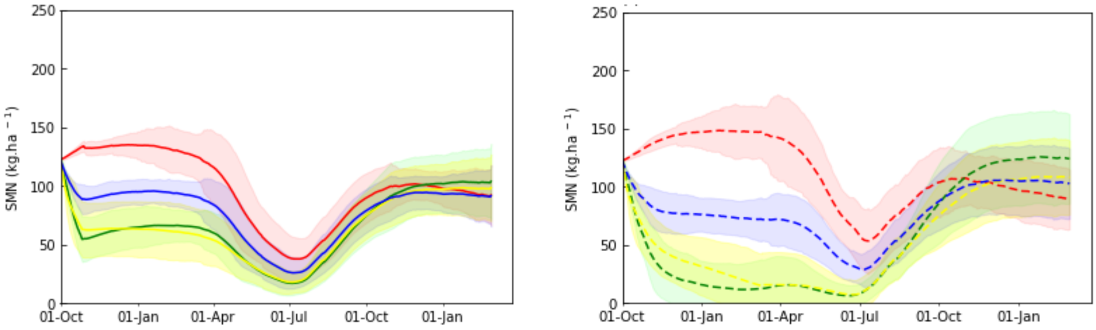

Figure 1: Average SMN dynamics (kg N ha^{-1}) for fall management scenarios in OF, with short (left) and long (right) fallow period, in plot p36 for B years. Scenario color code: bare soil = red, mustard catch crop = green, vetch-barley mixed catch crop = yellow, pure vetch catch crop = blue. Colored areas = mean ± standard deviation of climatic years.

This approach coupled in a dynamic and educational way the use of a model to quantify biogeochemical flows of interest and expert knowledge of farmers and advisers to design alternative scenarios. It allowed some shifts in N management practices after alfalfa in our network. This coupling could be enriched with other tools, such as OdERA-Systèmes, which indicates weeds risk at the scale of a rotation (http://www.agro-transfert-rt.org/outils/odera-systemes-2/). Integrating STICS into a user-friendly interface would ultimately enable supporting modelling to design cropping systems inorganic farming.

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