Improvement of the Hi-sAFe Model

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Contents

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1 Context

The AGFORWARD research project (January 2014-December 2017), funded by the European Commission, is promoting agroforestry practices in Europe that will advance sustainable rural development. The project has four objectives:

1. to understand the context and extent of agroforestry in Europe,
2. to identify, develop and field-test innovations (through participatory research) to improve the benefits and viability of agroforestry systems in Europe,
3. to evaluate innovative agroforestry designs and practices at a field-, farm- and landscape scale, and
4. to promote the wider adoption of appropriate agroforestry systems in Europe through policy development and dissemination.

The third objective is addressed partly by work-package 6 which focuses on the field- and farm-scale evaluation of agroforestry systems and innovations. One of the models being used for simulating agroforestry systems is Hi-sAFe which was originally developed under the SAFE project (Dupraz et al. 2005).

Hi-sAFe is a mechanistic model to simulate tree and crop productivity in agroforestry systems, taking into account the 3-D structure of the system. The objectives in developing the model were to help understand the functioning of agroforestry systems by accessing intermediary variables that are difficult to measure experimentally, and to predict the long-term effect of management options (e.g. different geometries of tree planting) in different soil and climate conditions. The development of the Hi-sAFe model started during the SAFE European project (2000-2005), was much improved by G. Talbot during his PhD thesis (Talbot 2011), but it was stopped later due to lack of human resources.

During the initial stages of the AGFORWARD project, improvements were still needed before Hi-sAFE could be distributed among the partners of the project and used to simulate innovative agroforestry systems. This milestone reports on the improvements made to the model up to July 2016 plus anticipated further improvements to i) make the model more reliable, ii) allow its widespread distribution, iii) facilitate virtual experiments, and (iv) increase the range of systems that can be simulated.

2 Model verification and calibration

The first step in the improvement of Hi-sAFe was to stabilize the code and detect the cause of fatal errors that appeared randomly and blocked code execution. Thorough scrutiny of the code allowed the identification of the error as an imprecise number representation in C language, and this was corrected. The improvement also included a close examination of the code to optimise memory allocation and disk read/write operations to improve the code performance and reduce computation time.

The Hi-sAFe model had only been verified in a limited number of situations. Hence new verifications were carried out for different soil conditions such as with or without a water table, and with and without stones. In experimental research in Southern France, walnut trees were sensitive to the depth of the water table. The highest growth rates are observed when the water table fluctuates between 2 m depth in winter and 4 m depth in summer. Lower growth rates were observed when the water table is higher (1 m deep in winter, 3 m in summer) or deeper (5 m in winter, 8 to 10 m in summer). With the previous calibration, the model was only calibrated for the initial situation and was not able to simulate properly the impact of the depth of the water table.

This tree's water uptake and response to water stress processes were therefore recalibrated using data from four experimental plots on the Restinclières Estate near Montpellier in southern France. The plots comprised one forestry control and three agroforestry plots with different soil and water table depth conditions, with 19-year old walnut trees. The calibration led to the modification of eight parameters within the model and the model now provides better descriptions of tree growth for three of experimental plots. Even so the new set of parameters is not fully satisfactory as it does not reproduce entirely the difference of tree growth observed with a deep water table (but it does predict the reduction of growth).

Future work: future work is anticipated to include removing the aggregation/disaggregation routine for soil calculations. This routine was included because the STICS crop model simulates soil processes on 1 cm thick soil layers (called ”minicouches” in French), while the Hi-sAFe model produces results on voxels that are thicker (usually 20 cm). This routine is very time consuming and induces the risk of rounding errors at each daily iteration. The increasing size of computer memory capacity now allows computations for 1 cm thick layers. The consequence will be a significant increase of the size of the tables that contain the soil variables, and it is necessary to ensure that this does not reduce the speed of the simulation process to a critical level.

3 Model distribution and documentation

Installation of the Hi-sAFe model used to require the intervention of an IT specialist to set up all the necessary files and compile the C code for the crop growth and soil processes module. This reduced the possibility to make the model available to a wide audience. Furthermore, the model was working only on a 32-bit version of Microsoft Windows. The workaround for this problem was to use a virtual windows machine on other operating systems, but it was complicated and led to difficulties with data extraction.

To solve these problems, we set up a procedure to compile all necessary librairies in Mac, Linux, and 32-bit and 64-bit version of Microsoft Windows. We also developed an installer to facilitate installation on new machines as well as version upgrading. The 32-bit Windows version may not be maintained, as most Windows-based computers use a 64-bit version.

Another problem limiting model distribution was that there was no systematic documentation about the model (in particular for the formatting of inputs and the interpretation of outputs). As a result, the model was usable only by the team who developed it. The documentation was improved, and there are now user guides (quick start to install and run the model in graphical user interface and a full user manual), as well as powerpoint presentations of the key steps to install the model and run simulations. All these documents will be included in Deliverable 6.16 (Update on the Hi-sAFe model)

Because of these improvements, we were able to distribute the model to twelve researchers who attended a Hi-sAFe workshop in Montpellier betwen 18 and 20 May 2016. An objective of the workshop was to allow partners within the AGFORWARD project to use the model (Figure 1). The participants used a range of operating platforms including Windows, Mac and Linux. The new version of Hi-sAFe could be installed and used on all three systems. At the end of the three days, the quickest participants were fully autonomous on the use of the model and even proposed improvements. Even the slowest participant was able to run the model in the graphical user interface and interpret the model outputs.

Figure 1. Paricipants during the HisAFe workshop held at Montpellier between 18 and 20 May 2016

4 Using the model to perform virtual experiments

Before the start of the project, the Hi-sAFe model could already be run in two different modes: in a graphical user interface, usable by inexperienced users to run a single simulation and observe the outputs easily with standard plots, and in "batch mode", allowing expert users to run multiple simulations without human intervention. However, the batch mode presented several drawbacks limiting the use of the model to perform virtual experiments.

The first drawback was that the export profiles to save model outputs to disk were partly hard-coded so that the user could not easily choose the variables for export and could not adapt the output frequency to find the best trade-off between the frequency needed to answer questions and the execution time. This problem was solved by making the export profile fully flexible. There is now a choice of variables and export frequency for each set of variables, even giving the possibility to vary the frequency with time (e.g. to export the simulated variables every day during the first years of tree growth and then each month or even each year when the trees are mature).

The second drawback was that the necessary input files (e.g. crop and tree parameters, soil characteristics, and climate scenarios) were dispersed in several folders, making it difficult to keep track of which file was used for which simulation. This problem was solved by gathering all files in a single folder for each simulation, which also contains the model outputs. As a result, each simulation

is now fully traceable, which improves the reliability of the results. It is now possible to run again a simulation that was performed in the past, and, for example, to export new variables that were not included in the previous outputs.
The last major drawback was that it was quite tedious to set up all the files necessary to run multiple simulations. This has been addressed by writing R scripts to help generate input files according to an experimental design and to launch the simulation, as well as to combine the results from the different simulations into a single file ready for analysis.

Because of the above improvements, it was possible to perform the first systematic virtual experiment with the model. The objective was to test the assumption that light competition is more detrimental to crops at high latitudes than low latitudes, which is often put forward to explain the relatively greater success of agroforestry at tropical and Southern Mediterranean latitudes. To this end, we performed 40 simulations comprising five latitudes ranging from 25 to 65°N for each of two tree row spacings and for each of two tree row orientations. The results were compared in terms of relative irradiance available to the crops and the heterogeneity of the irradiance across the crop alley which is important for crop maturation and harvest.

The results indicated that silvoarable agroforestry could be implemented at each of the studied latitudes. The results also provided guidance for optimising the design of alley-cropping systems. For example: reduced light heterogeneity in the cropping alley can be achieved by using a north-south orientation of tree lines at high latitudes (>50°). By contrast maximizing the crop irradiance during grain-filling period (spring for winter crops, summer for summer crops) can be achieved by using an east-west orientation of tree lines at low latitudes (<40°). These results have been presented as an oral presentation at the Third European Agroforestry Conference in May 2016 (Dupraz et al., 2016), and as a paper that will be submitted shortly to Agroforestry Systems.

Future work: one improvement to help running virtual experiments, that could be added to Hi-sAFe, is the possibility to save and relaunch a simulation from starting points other than tree planting. This would allow users to simulate agroforestry system for a certain time and then simulate different management options (e.g. tree pruning) or soil and climate conditions (e.g. different climate change scenarios) without having to run again for the same initial years.

5 Improvements to the model

Before the start of AGFORWARD, the Hi-sAFe model had been used to simulate only very simple scenarios, i.e. one tree (usually hybrid walnut) at the centre of the simulated plot and the same crop (usually durum wheat) grown year after year. This was acceptable to simulate very simple agroforestry systems such as those that were set up at the beginning of the development of modern agroforestry in Europe. However, farmers are now testing new innovative systems that are much more complicated in terms of tree species (alternation of different tree species between rows or even along the tree row) and choice of crops (not only crop rotations but also mixtures of different crop species at the same time). Several modifications were necessary to make the model suitable for the simulations of these innovative systems.

Crop rotation (i.e. succession of different crop species year after year) was possible only in graphical user interface (GUI) mode: the user had to set up the first year of simulation, manually change the crop to run the second year and so forth. Given the time necessary to run each year in GUI, this made it very difficult to simulate crop rotations for more than a few years. We modified the model to make it possible to simulate arbitrary rotations in batch mode, with the possibility to have both winter and summer crops (which required changing also the format of the climate input files). This improvement is fully functional, except for perennial crops like alfalfa because of a problem in rooting pattern initialisation, but this problem should be solved with the upgrade to STICS V8 (see below).

Before the AGFORWARD project, the model had not been tested with planting patterns other than a single tree, or two trees of the same species aligned in a row. Tests with more complicated patterns (including arbitrary patterns with different species) were carried out by participants to the Hi-sAFe AGFORWARD workshop, who detected errors with some patterns with trees at the border of the plot. The model has since been improved to accommodate a wide range of planting patterns. The work being done currently to upgrade the crop module of Hi-sAFe, which was based on the crop model STICS version 5, to STICS V8 should introduce into Hi-sAFe all the new features of STICS, including new crops and, most importantly, the possibility to simulate crop mixtures.

Further work: other improvements of the conceptual model are being considered. First, with the strong emphasis of agricultural research on the effect of climate change, taking into account the effect of an increased level of CO_2 is becoming important. This effect is already taken into account for crop growth, it might be necessary to introduce it also for tree growth. Other effects that could be added in the model are capillary rise of water from the water table to higher layers of soil (this is the process of hydraulic lift which allows the tree to "pump" water in deep layers of soil and release it near the surface during the night). Another effect that could be added is the possibility to simulate tree pollarding i.e. the process of cutting all the branches of a tree regularly, to produce firewood and reduce light competition with crops. Without going into such modifications of the conceptual model, improvements that would also greatly increase the range of systems that can be simulated also include the calibration of new tree species. Interest was expressed among AGFORWARD partners for Paulownia (in Hungary) and Oak (in Portugal), but it is not yet clear if all the data necessary to calibrate these new species is readily available.

6 Conclusions

The Hi-sAFe model has been largely improved during the course of the AGFORWARD project, both in terms of code efficiency and reliability and in terms of user friendliness and suitability to a wide range of applications. The keen interest in the model potential use showed by some of the participants of the AGFORWARD Hi-sAFe workshop bodes well for the usefulness of the improved model for the AGFORWARD partners. We also have identified a number of future possible improvements that could further enhance the simulation of innovative agroforestry systems.

7 Acknowledgements

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8 References

Dupraz C, Lecomte I, Molto Q, Blitz-Frayret C, Gosme M (2016). Agroforestry at all latitudes? Unexpected results about best designs to allow more light to the crops at various latitudes. Presentation made at the Third European Agroforestry Conference, Montpellier 23-25 May 2016. http://www.agroforestry.eu/conferences/III_EURAFConference

Talbot G (2011). L'intégration spatiale et temporelle du partage des ressources dans un système agroforestier noyers-céréales : une clef pour en comprendre la productivité? PhD Thesis. Ecosystemes. Universite Montpellier II - Sciences et Techniques du Languedoc. Accessed 22 July 2016. https://tel.archives-ouvertes.fr/tel-00664530

Annex A. Reports describing the improvement of Hi-sAFe

The improvements of the Hi-sAFe model completed between May 2015 and June 2016 are described in nine reports that are available at the following internet address :
https://www.dropbox.com/sh/b2x59m0khd4x6em/AADr_6OTB-lyd3n1t8SDdlJ8a?dl=0

These reports are mostly written in French, with some parts in English. The reports are:

Lecomte I (2015a). Stabilisation du code. Livrable N°1. Evolution et valorisation du modèle de simulation agroforestier Hi-sAFe. 29 May 2015. 6 pp.

Lecomte I (2015b). Module d’exportation permettant des sorties à des fréquences différentes pour les différents objets. Livrable N°2. Evolution et valorisation du modèle de simulation agroforestier Hi-sAFe. 1 July 2015. 5 pp.

Lecomte I (2015c). Modèle opérationnel pour des rotations de culture. Livrable N°3. Evolution et valorisation du modèle de simulation agroforestier Hi-sAFe. 2 September 2015. 8 pp.

Lecomte I (2015d). Modèle opérationnel pour les sols avec et sans nappe. Livrable N°4. Evolution et valorisation du modèle de simulation agroforestier Hi-sAFe. 29 September 2015. 9 pp.

Lecomte I (2015e). Jeu de paramètres standard pour les simulations noyer-blé à Restinclières. Livrable N°5. Evolution et valorisation du modèle de simulation agroforestier Hi-sAFe. 10 November 2015. 11 pp.

Lecomte I (2015f). Simulations de référence pour parcelles A2, A3 et A4 de Restinclières permettant la calibration du modèle. Livrable N°6. Evolution et valorisation du modèle de simulation agroforestier Hi-sAFe. 22 December 2015. 17 pp.

Lecomte I (2015g). Simulations pour les publications « effet de la latitude » et changement climatique. Livrable N°7. Evolution et valorisation du modèle de simulation agroforestier Hi-sAFe. 22 December 2015. 10 pp.

Lecomte I (2016a). Modèle opérationnel pour des sols avec ou sans cailloux. Livrable N°8. Evolution et valorisation du modèle de simulation agroforestier Hi-sAFe. 4 April 2016. 13 pp.

Lecomte I (2016b). Rapport sur les perspectives pour faire évoluer le modèle. Livrable N°9. Evolution et valorisation du modèle de simulation agroforestier Hi-sAFe. 11 April 2016. 6 pp.