DigitAF Deliverable 2.5: Plan for improvement of existing tools/models for tree and crop productivity

Marie Gosme, Tom De Swaef, Christian Dupraz, Marc Jaeger, Karen Lammoglia, Maryline Laurans, Isabelle Lecomte, Magali Pellissier, Benoit Ricci, Clément Rigal, et al.

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Improving tools for practitioners

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Deliverable	Deliverable 2.5: Plan for improvement of existing tools/models for tree and crop productivity
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Authors	Marie Gosme, Cécile Antin, Tom de Swaef, Christian Dupraz, Marc Jaeger, Karen Lammoglia, Maryline Laurans, Isabelle Lecomte, Magali Pellissier, Benoit Ricci, Clément Rigal, Victor Rolo, Marc Saudreau, Nathalie Smits, Alexia Stokes, François Warlop
Contact	Marie.gosme@inrae.fr
Approved	Tom De Swaef (8/12/2023) Bert Reubens (8/12/2023)

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Contents

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1 Context

The DigitAF research project (July 2022 - June 2026), funded by the European Commission, aims at a high-quality implementation of agroforestry to foster climate change mitigation and adaptation in agriculture and to ensure sustainable management of natural resources. Our goal is to provide the main actor groups with tools answering their needs, in particular digital tools. The three actors' groups that are target by DigitAF are:

- Policy actors: policymakers and administrations concerned with applying agroforestry -related regulations, at regional, national and European levels, who set the scene for the adoption (or not) of agroforestry.
- Practitioners: farmers, landowners and by extension, farm advisers playing an active role in designing and managing AFS and whose choices determine the agronomic, economic, environmental, and social performance at farm-level and beyond.
- Beneficiaries of AF products and services: stakeholders in the value chain, including wholesalers, retailers, organisations trading the carbon sequestration and biodiversity benefits of AFS, and final consumers seeking verification of the benefits of AF in clear and accessible terms.

This report is relevant for the second stakeholders' group. It presents our plans for improving existing tools and models used to predict tree and/or crop productivity (and potentially other performance indicators) in different conditions of soil, climate (including climate change), type of system, management, etc. .

The envisioned improvements fall into 2 categories:

- Improving the reliability of the models and tools to fulfil adequately the practitioner's needs identified in the surveys performed in the Living Labs. This requires including new formalisms to represent e.g. management options that the practitioners wish to compare, or adapting or testing models/tools to new conditions.
- Improving the FAIRness score of models and tools, according to the FAIRness criteria developed in WP4. Particular focus has been put on interoperability, because the models were developed somewhat independently, often several years ago and did not have a web 2.0/3.0 concept in mind. Therefore, there are limited data sharing standards to describe AFS and allow interoperability between the different models and tools. This results in duplicate data entries, difficulties for using outputs of one model as inputs for another one, and the impossibility to reuse modules of one model in new models. Another important aspect that we'll focus on is improving the usability of tools, based on feedback from the stakeholders in the Living Labs.

Tools adapted/developed during the project will serve as demonstration vectors for engagement towards the FAIR principles to boost their usage and applicability between peers (other researchers, students, etc.) and downstream marketable applied tools.

2 Improving the reliability of models and tools

2.1 Hi-sAFe, a tree-crop mechanistic model for temperate agroforestry systems

Hi-sAFe (Dupraz et al. 2019) is a daily time-step, 3D, soil-crop-tree model. It predicts crop and tree growth and yield, as well as some environmental performances, as a function of pedoclimatic conditions and tree and crop management, taking into account tree-crop competition for light, water and nitrogen. The model has been developed for several years, and has been the basis for several publications (Dupraz et al. 2018; Huo et al. 2021), including simulations of climate change (Reyes et al. 2021). However this last publication only focused on crop growth, because **Hi-sAFe** is not yet well adapted to simulate the effect of climate change on tree growth, and only studied the effects of trends in climatic variables, not the effect of extreme events. To answer practitioners' questions about the adaptation of agroforestry systems to climate change, the model could be improved on two aspects.

2.1.1 MICROCLIMATE

As in any models, **Hi-sAFe** is based on assumptions that simplify processes to make the model as simple as possible, but still detailed enough in the processes of interest for a given question. With the advent of more frequent extreme events due to climate change, the focus has changed from simulating the effect of the trends in climatic variables to simulating the effects of extreme events such as heat waves or prolonged droughts. This might require improvements of the model, for instance concerning tree canopy representation and tree-crop water relations. Indeed, as already pointed out by Talbot and Dupraz (2012), the use of a simple 3D representation of the tree canopy through an ellipsoidal shape where leaves are randomly distributed present some limitations in estimating light transmitted by trees. This limitation can be problematic when one wants to quantify the ability of AF system to mitigate heat waves with the **Hi-sAFe** model. To improve this point, **Hi-sAFe** will be compared with a detailed model of tree and crop microclimate (light transmitted and leaf surface temperature) based on the RATP model (Sinoquet et al. 2001) . Furthermore, the effect of water stress in plants is currently represented in the model by stress indices that reduce physiological processes, but do not kill the plant. Episodes of extreme drought might make this an over-simplification. We'll use the Sureau plant hydraulic model (Cochard et al. 2021) and compare its outputs to **Hi-sAFe**'s outputs. This comparison will estimate errors made by **Hi-sAFe** on light transmitted to the crop and on the effect of extreme drought on plants (more specifically wheat) and will determine whether it is necessary to improve **Hi-sAFe** model, and guide future improvements of the **Hi-sAFe** model.

2.1.2 CO_2 EFFECT ON TREE GROWTH

To improve the ability of the model to predict the impact of climate change on agroforestry systems, we need to represent the fertilising effect of an increased atmospheric concentration on tree growth (the effect of CO_2 concentration on crops is already taken into account in STICS, on which **Hi-sAFe** is based to represent crops). This can be done by increasing the Light Use Efficiency and decreasing the Water Use Efficiency. We will therefore introduce two new equations in the model, to modulate LUE and WUE as a function of CO_2 concentration.

2.1.2.1 CO_2 EFFECTS ON THE LIGHT USE EFFICIENCY (LUE)

Plant growth and photosynthesis generally have saturating responses to atmospheric CO_2 concentrations (Ca) over CO_2 concentrations between 300-800 ppm, and these can reasonably be approximated with a Michaelis–Menten equation. This CO_2 response in the **Hi-sAFe** model needs to be scaled so that it takes a value of 1 when Ca is equal to the concentrations when the model was calibrated (e.g., about 370 ppm in the year 2000, and now almost 420 ppm). We suggest using the following formulation:

$$CO2lue = \frac{Ca}{CO2calib} \cdot \frac{KmCO2 + CO2calib}{KmCO2 + Ca}$$

Where:

- $CO2lue$ is the multiplicative factor to apply to the LUE equation. It equals to 0 when $Ca = 0$, to 1 when $Ca = CO2calib$, and is higher than 1 when $Ca > CO2calib$
- Ca is the atmospheric CO_2 concentration
- $KmCO2$ is the half saturation constant (same units as Ca)

- $CO2calib$ is the Ca when the model was calibrated (same units as Ca)

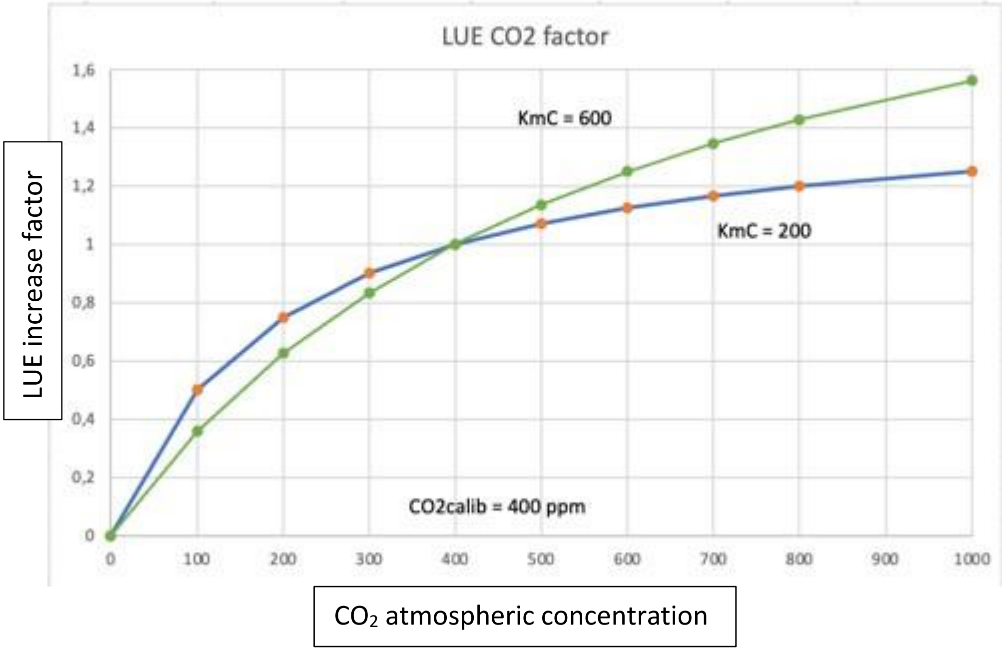

Figure 1: CO2lue as a function of Ca, assuming that the Hi-sAFe model was calibrated at 400 ppm.

2.1.2.2 CO_2 EFFECTS ON TREE TRANSPIRATION (WUE)

Intrinsic water use efficiency (iWUE = net photosynthesis / stomatal conductance) nearly always increases in plants as Ca rises due to stomatal control of Ci/Ca. The iWUE response to changes in Ca is fairly robust based on historical trends and elevated CO_2 experiments at least in C3 plants (e.g., Ainsworth & Long 2005, Mathias & Thomas 2019). Historically, rising Ca accounts for about 60% of the measured variation in iWUE in trees across a very wide range of conditions (Mathias & Thomas 2019). However, the part of changes in iWUE due to increasing net photosynthesis vs. stomatal closure varies greatly and is the subject of considerable debate. The approach we are suggesting takes advantage of this iWUE response to CO_2 and formulation of the Pereira et al. (2006) model used in the tree potential transpiration module of **Hi-sAFe**. We are assuming that the CO_2 response of LUE (section 2.1.2.1) and iWUE can be used to derive a multiplier for the Pereira model. The formula below gives a transpiration modification factor of 1 to the CO_2 concentration at which the model was calibrated. The formula below assumes that the sensitivity of iWUE is constant over a reasonable range of Ca (i.e., 300-700 ppm) which seems a good first approximation (Mathias & Thomas 2019). But we can easily change this by making iWUEsens a linear function of Ca instead of a constant.

$$iWUE = 1 + iWUEsens \cdot \frac{Ca - CO2calib}{CO2calib}$$

$$CO2trans = \frac{CO2lue}{iWUE}$$

Where:

- $iWUE$ is the intrinsic Water Use Efficiency
- $iWUEsens$ is the sensitivity of iWUE to changes in atmospheric CO_2 concentration and it has a historical value of about 1.2 (i.e., at 100% increase in Ca gives a 120% increase in iWUE).

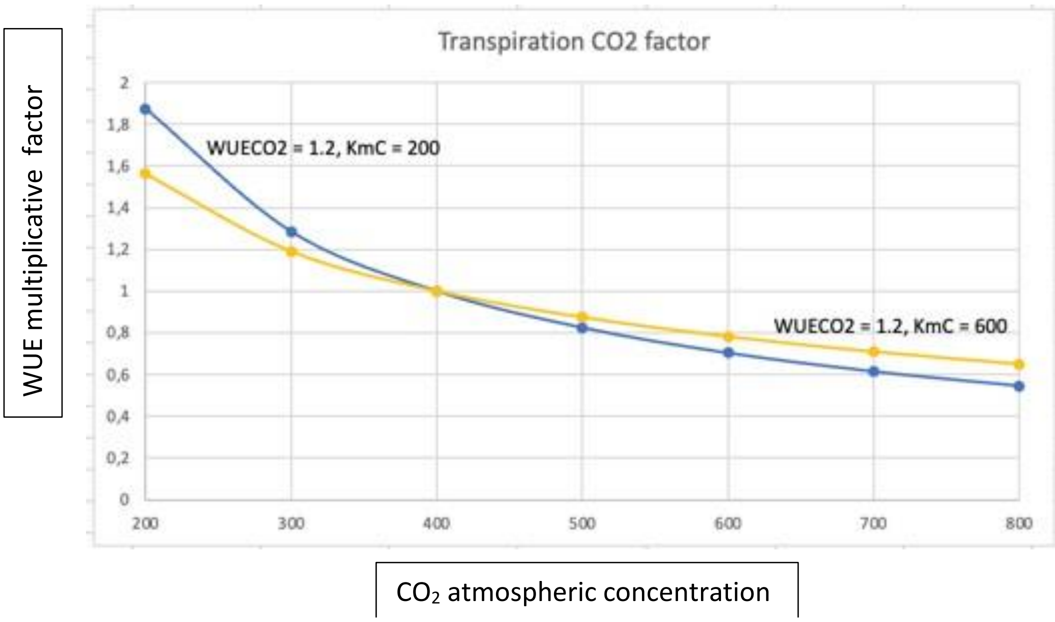

Figure 2: CO2trans as a function of Ca using a value of iWUEsens = 1.2 and the two CO2lue equations in panel a. Note that WUECO2 = iWUEsens in the equations above. Note the change of scale of Ca on the transpiration factor graphic.

2.2 WaNulCas, mechanistic model for tropical agroforestry systems

WaNulCas, a mechanistic model initially developed for tropical agroforestry systems, is crucial in simulating and predicting the productivity of key tropical crops such as cocoa and rubber. This model stands out for its ability to simulate complex interactions between trees and crops, considering variables like light competition and nutrient cycling.

Our approach involves a comprehensive comparison between **WaNulCas** and **Hi-sAFe**, particularly focusing on their application in cocoa and rubber cultivation in agroforestry systems. We aim to leverage the strengths of each model while acknowledging their limitations. The data collection, pivotal to the parameterization of **WaNulCas** and **Hi-sAFe**, has already been initiated and is ongoing, using datasets from previous projects (RUBIS Project and the project Cocoa4Future).

The comparison will include testing the ease of creating input files for both models, ensuring that the process is intuitive and user-friendly for practitioners. Additionally, we will access the precision of each model's outputs by comparing them to measured values.

By doing so, we aim to pinpoint the formalisms that require enhancement and identify the crucial modifications needed. These improvements are imperative to ensure that either model can be effectively utilized for simulating tropical agroforestry systems.

2.3 AgroforestAR, a tool to help design agroforestry systems with Augmented Reality

AgroforestAR is a suite of modules to allow capturing the composition and configuration of an agroforestry system based on physical tokens such as those used in mock-ups used in design workshops, building a formal representation of the system, and finally visualizing the system in augmented reality (Lemière 2023). The prototype is available on GitHub (https://github.com/agroforestar) but it is not yet complete, since the different modules (capture, formalisation, visualisation) are not yet integrated in a single app. In DigitAF, we develop a prototype to demonstrated the possibilities of augmented reality to communicate about agroforestry with farmers.

2.4 Predicting the link between biodiversity and production of ecosystem services

In AF systems, the choice of tree species has an impact other ecological communities, in particular the under storey flora, arthropods, birds and bats, with consequences on ecosystems services such as the biological regulation of crop pests and pollination. However, the knowledge concerning these relationships is still patchy. In this part, we intend to map existing knowledge (scientific corpus, empirical or embedded in advisory tools) and to propose a unified framework that could be used as a plug-in of other existing tools. This last aim is partly shared with the section 3.2 “Tree selection tools” and 3.3 “Knowledge Base” with a focus onproviding information on ecosystem services at different spatial scales. Links will be made also with the biodiversity evaluation tool developed in WP3 of DigitAF.

2.5 Developing pest/disease models for agroforestry

Any crop which is associated with trees develops under a specific microclimate. This microclimate also influences the pests and diseases possibly developing on the crop. In this task, we will check for microclimate models in agroforestry systems and, on one given example, try to link the microclimate model with an epidemiological model, to estimate the difference in pest / disease risk between the crop monoculture situation and the agroforestry situation.

Another possible avenue for developing pest/disease models would be to adapt the methodology developed by Tosh et al for English silvoarable systems (Tosh et al, 2024) to other contexts. This methodology uses a Boolean Regulatory Network framework, initially developed for gene regulation networks, representing elements of the system as “nodes” in a graph, each node having only two possible states (absent/present, or low/high). Interactions between elements are represented by directed edges (=arrows) in the graph. The probability of each node to change state during a given timestep is determined by the state of all causal nodes (i.e. all node with an arrow pointing to the focal node). This type of model allows representing the complex dynamics of systems with many interacting elements, while at the same time being simple enough to allow parameterisation by expert opinion. In order to explore the possibility of using this type of model, we will develop a GUI allowing to play with the existing model and build new models adapted to other context and/or other problems. We will then parameterize new/adapted models within the interested living labs.

2.6 Characterising the chemical landscape and its effect on pests and beneficial arthropods

ACTA (ITEIPMAI) will work on the chemical landscape created by aromatic plants, which affects insects’ behaviour. These tools will be improved in close collaboration with the LL, using field evidence. The first stage involved to design a prototype. A benchmarking was carried out to find the more appropriate equipment. In the absence of suitable and ready-to-use equipment, the different parts of the system have been bought, then have been assembled. The instrument thus obtained is inexpensive, light, robust, easy to transport and to use in the field.
First laboratory tests have produced encouraging results. The tool now needs to be calibrated before it can be tested it in the fields.

Figure 3: picture of the tool developed by ITEIPMAI. It comprises a pump and a support for capturing the volatile organic compounds (VOCs) emitted by the plants. After extraction, we obtain a volatile compound profile. This profile is then analysed as a parameter to be taken into account in the study on the impact of inter-rows in agroforestry.

2.7 Improving the performance of trees

The analyses of the first results of the survey conducted among the 6 Living Labs (LL) (Deliverable 4.1 - Inventory of stakeholders needs and expectations), highlighted that the level of knowledge regarding the management of trees and their performances was perceived as a potential technical obstacle in 4 Living Labs (LL). According to the respondents, new tools may be useful for tree performance predictions (5 LL) and tree management (4 LL), for example for tree pruning (3 LL), tree health diagnostics (2 LL) and productivity optimization (1 LL). The most adapted tools may be decision support tools (4 LL), collaborative tools for knowledge diffusion (4 LL), visualization tools (2 LL) and tools that can be used for teaching (1 LL).

The inventory of tools dedicated to tree management in agroforestry made it possible to identify 33 digital tools and models, as well as 48 other resources (guides, technical sheets, training, etc.). Among them, numerous digital tools that have been finalized or are under development are dedicated to the design of agroforestry systems (19), including the choice of species (5). Within DigitAF, subtasks on these aspects are already conducted by EV ILVO, INRAE and other partners for species selection and UEX for optimal density. A working group, “Tree species selection tools for AF - towards a joint approach” has been created specially to deal with the choice of species. Therefore, aspects linked to design and species selection will therefore not be discussed hereafter. We also found many tools dedicated to carbon storage estimation (8). This issue will not be addressed in our work either, as it is already handled in Task 3.4.
On the other hand, we found few decision support tools dedicated to the management of trees from planting to harvest (4). We found only one tool dedicated to the evaluation of the future value of trees in terms of wood quality (Grille TBS, not maintained) and a tool for predicting tree growth from one or two girth measurements a few years after the plantation (DiAFnostic, in development). As well, we found only one tool dedicated to tree vigour and stress diagnosis (DiagARCHI) but it was developed for forest trees and needs adaptations for use in an agroforestry context. We finally found a practical

hedge management tool based on an initial diagnosis made by an advisor and the implementation of a planning for the operator (PGDH, in use).

Most of the other resources listed on tree management are guides (7), technical sheets (4) or training courses (16) giving technical advice for tree plantation, pruning or harvest. These resources are numerous and accessible, and yet, at first glance, there seems to be a lack of management of trees so that they achieve the expected performance, in particular for the production of quality timber. This assessment brings several questions regarding the harmony between resources and needs. What is missing? Should the accessibility, the training or the content of the resources be improved?

A preliminary analysis of the content of the resources showed that the tree development state is poorly taken into account in the technical advice. We made the hypothesis that including the diagnostic of tree vigour and stress in a decision support tool or in other resources dedicated to tree management could help optimize tree performances. For example, it could help to adapt pruning operations according to tree development by giving the operator simple architectural criteria to take decisions.

We identified several situations in which the architectural approach can be applied:

- diagnosis of seedlings before planting to help with seedling selection, or even to improve nursery growing methods,
- diagnosis of recovery in the first few years after planting (Figure 4), to help monitor plantations,
- diagnosis of trees installed following a recent planting, to help in the decision-making process for pruning operations and for the reorientation of poorly conformed trees.

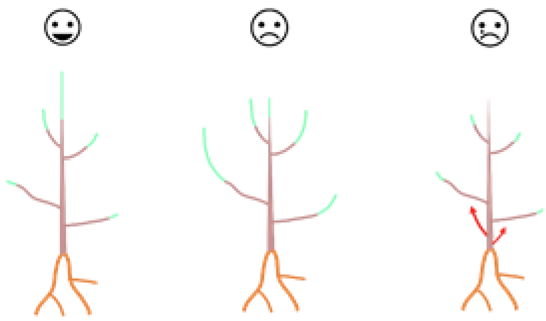

Figure 4: The location and intensity of growth (in green) and the reaction (in red) are good indicators of tree regrowth

To determine how the architectural approach could make an effective contribution to tree management, we conducted a series of semi-structured interviews with twelve stakeholders in the development of agroforestry in France in order to clarify the issues and expectations of stakeholders in the field with regard to tree management. We chose to contact advisors, technicians, trainers and researchers, on the assumption that this would enable us to summarise farmers' observations and needs at a local, regional or national level, depending on the role of the interviewee. The interviews, lasting between one and two hours, were conducted by videoconference between October 2023 and February 2024. They were also used to complete the initial inventory of tree management tools.

We conducted a qualitative analysis of the responses and found that:

- In France, various stakeholders may be involved in the management of field trees and hedges, depending on the stage of management. Consequently, improving the management of field trees requires identifying all the stakeholders involved locally and mobilising them in ways that are appropriate to each situation.
- The performance expected of trees relates more to ecological services than to production. In particular, timber production appears to be a very minor objective for recent plantations.

- The management of existing trees is considered highly unsatisfactory and seems to compromise the expected ecosystem services in the case of hedges, and the timber production objectives where they exist.
- Many resources already exist for tree management. The main obstacles to good tree management are the lack of knowledge about trees and the lack of available labour.
- The architectural approach is little known among the people interviewed and is not used in current tools.
- the proposal to apply the architectural approach in the form of a diagnostic tool to aid decision-making was generally perceived as being too technical
- the participants' expectations focused more on improving knowledge of trees through research and passing on this knowledge through training and awareness-raising.

These results were submitted to the Living Labs leaders for comparison to the specific situations in each Living Lab. Their feedbacks emphasized that tree management is poorly taken into account at the present stage of agroforestry development in the different Living Labs, and that expressed needs focus more on system design and plantation.

In order to anticipate the questions about the management of trees, that will inevitable emerge once the recently planted trees will grow, we are therefore going to propose to Living Labs an analysis grid for establishing a local diagnosis of tree management issues and resources. We will base our analysis on observations drawn from interviews conducted in France. We will also produce an educational reference framework on training needs for tree management.

2.8 Improving tools to select tree species

Selecting the right tree for an agroforestry project goes beyond selecting the right species. It often also implies considering the right cultivar and/or rootstock, or considering the suitability of the tree species under quickly changing climatic conditions. ILVO will tackle both aspects.

Cultivar selection is particularly important for fruit and nut producing trees. ILVO established two long term experimental trials with hazelnut and with walnut trees. The walnut trial - focusing on late budding varieties - is installed at several locations. More information can be found here. The hazelnut trial is installed within a silvopastoral agroforestry system since 2017. More information can be found here. The trees on these sites are monitored during (and before) the DigitAF project period, and the results in terms of cultivar performance, growth, productivity, health, etc. will be reported, both in a technical report and as A1 publication. The data will be available for potential use in digital tree selection tools.

As for the selecting the right trees under changing climatic conditions, ILVO is performing a thorough literature review and will publish guidelines under the form of a digital factsheet. A first draft, in Dutch, is already available online (here). This will be further elaborated and made available in English as well.

Pervasive water shortages and drought extremes are expected to increasingly affect tree production. This is particularly important for Mediterranean agroforestry systems that are limited in a great extent by water availability. For instance, acorn production of Mediterranean silvopastoral systems, located in the SW Iberian Peninsula, is dependent on the level of stress that trees suffers during the dry period (Carevic et al. 2010). Similarly, at high tree densities, competition between trees compromises their functioning and production (Forner et al. 2020). According to the optimal equilibrium hypothesis, there is an optimal tree density that maximizes biomass production at a given water stress (Joffre et al. 1999) . However, it is uncertain that this equilibrium is reached due to local factors, such as management, or global change components, such as climate change (Natalini et al. 2016). UEx will used eco-hydrological models to assess the optimal tree density under current and future climatic conditions, using as a case study Meditarranean silvopastoral systems. UEx will follow a similar approach than previous works of the group, where the model 'medfate' was successfully calibrated to simulated competition for water resources in Mediterranean silvopastoral systems (Rolo and Moreno

2019). Given the flexibility of the model, this approach is extensible to other agroforestry systems. UEx is performing the calibration of the model for the study site Majadas de Tiétar. The proposed plan is to simulate a range of tree densities under future climatic conditions. Tree growth and water yield will be assessed as response variables.

Tools for tree species selection developed for temperate climates differ from those developed for tropical areas, in that they draw on two very distinct knowledge bodies. There are many more tree species in tropical areas than in temperate areas and, in comparison to temperate species, only limited knowledge on them. Only a few tropical tree species are well documented: mostly the main fruit tree species (mango, avocado, etc.) and the few main timber tree species (Eucalyptus, Albizia, etc.). However, the majority of indigenous tropical tree species have rarely been studied in agronomy trials, and their growth pattern and interactions with other species are poorly understood. Yet, researchers have developed tools to support tree species selection in tropical areas despite these constraints. A usual technique used to fill the scientific lack of knowledge consists in relying on farmers' local ecological knowledge (for example (Fremout et al. 2021)). Tools based on farmers' knowledge manage to incorporate large databases of tree species and large arrays of tree species' impacts (over 160 tree species and 10 ecosystem services documented in **ShadeTreeAdvice** (Rigal et al. 2022). Tools developed for European farmers could benefit from this experience gained in tropical countries, both in terms of method for data collection and in terms of management of larger sets of species with limited information.

Furthermore, the **ShadeTreeAdvice** tool was developed in 2016 (Van Der Wolf et al. 2019) and, since its inception, the tool design evolved to incorporate new functions. The team in charge of the tool development spent considerable time thinking about the assets but also shortcomings of the online tool and its design, and possible ways forward to keep improving it. Some improvements were implemented while some others are still being discussed (Rigal et al. 2022). These topics include: representation of the results; links to sources of the information presented in the online tool; links to other existing databases to complete the missing information; difficulties to handle (local) names of species; possibility to make the tool dynamic with feedbacks from users; etc. The most important topic of all is certainly the one of multi-criteria analysis to select tree species that can bring multiple benefits to farmers, and getting tailored recommendations to farmers based on their own specific needs. Sharing this experience could also directly benefit the teams in charge of developing tools for European farmers.

Lastly, the **ShadeTreeAdvice** tool itself will benefit from the interaction with other decision-support tools developed for European farmers. The main avenue for improvement consists in fitting its data and algorithm into a broader framework, common to the different tools from the DigitAF Project (see section 3.2). This will not only improve inter-operability between tools, it will also reinforce the theoretical foundations behind the tools, such as the chosen framework to describe potential benefits from tree species in terms of ecosystem services.

Proposed plan:

- Sharing experience with other tool developers regarding:
  - Development and management of **ShadeTreeAdvice** (from a first website managed by an external firm to an app developed by the research team itself)
  - Use of **ShadeTreeAdvice** (target audience / actual use / feedbacks from users)
  - Multi-criteria analysis for tailored-made tree species recommendations
  - Knowledge management and limits (local ecological knowledge in this case)
  - Currently missing functions, that would benefit the tool and the users

- Inserting the database of ecosystem services into the new proposed framework common to the Digitaf Project. Cleaning the list of tree species.

2.9 Other tools being considered for improvement

On top of the previously mentioned tools/models, which were identified at the beginning, new ideas of tools to use and improve have come up during the course of the project:

- **AgroforesTreeAdvice** - this tool is presented in detail in section 3. because it illustrates well the principles of FAIRness.
- **CarboCatch**

3 Improving FAIRness and usability of models and tools

The «FAIRness score» concept is based on the FAIR principles (https://www.go-fair.org/), established in 2016, whose guidelines help to improve the Findability, Accessibility, Interoperability and Reusability of digital resources. These are fundamental aspects when trying to automate, connect and understand large volumes of dispersed and complex information. These high-level principles allow different communities to adapt and apply them to their context, although facing the challenge of not misinterpreting or distorting the original formulation. In DigitAF, we have applied these concepts and refined them in order to score the FAIRness of digital tools that policy-makers, farmers, agricultural extensionists, or stakeholders in the value chain of agroforestry services and products can use in relation to agroforestry development (See Milestone M16).

When applied to the «DigitAF Tool Database» (https://digitaf.eu/tools-database/), the «FAIRness score» will help users to better understand the state of development and openness of each tool. This automatically calculated, but human-verified, scoring system also works as a self-assessment for tool developers to understand their tool's strong points and improve their weaker spots. Its final goal is to help to increase accessibility and interoperability between tools whose developers seek continuous improvement.

3.1 Hi-sAFe

"FAIRisation" of **Hi-sAFe** is a specific objective of DigitAF. Therefore, we give below detailed descriptions of the planned steps to improve the FAIRness score of **Hi-sAFe**.

3.1.1 FINDABILITY

Currently, the code of **Hi-sAFe** has no persistent unique identifier. To make the repository easier to reference in academic literature, we will create a persistent identifier, also known as Digital Object Identifier (DOI). To do so, we will use the data archiving tool Zenodo to archive a repository on GitHub.com and issue a DOI for the archive.

The current documentation of the **Hi-sAFe** model is incomplete: it consists of a published article presenting the most prominent features of the model (Dupraz et al. 2019), an installation guide and a user guide (available on **Hi-sAFe** website (https://www1.montpellier.inra.fr/wp-inra/**Hi-sAFe**/en/) after registration). In the coming months we will make a big effort to describe the different scientific processes implemented in **Hi-sAFe** to have a complete documentation of all functions of the model.

The model is already easily findable by researchers, thanks to the aforementioned scientific article, and numerous citations in the scientific literature (31 citing articles referenced in Web of Science in November 2023). It is also referenced in the DigitAF tools database (https://digitaf.eu/tools-database/).

3.1.2 ACCESSIBILITY

Currently the **Hi-sAFe** model cannot be downloaded directly from the website. Interested users have to register their email and wait for one member of the **Hi-sAFe** TEAM to send the model and its documentation in the form of a .JAR archive. The JAVA code is not distributed. We plan to make **Hi-sAFe** (executable and source code) available for download on a GITHUB repository without registration under GPL license to make it freely available to the community. Its modification for non-commercial purposes will therefore be possible. The mention on the website "scientific publications using **Hi-sAFe** must have one of the **Hi-sAFe** team member as co-author, so please contact us before preparing your manuscript." will be removed.

The documentation will also be freely accessible. The website already contains the pages where this documentation will be presented, once completed (see previous section).

The requirements for running the model are not a constraint: the model runs on Windows, Mac and Linux (although installation on some Linux systems can sometimes be tricky for various reasons). The model is distributed as a .jar file containing its own installation wizard.

The model is only available in English, but this does not limit its accessibility for its intended users, who are mostly researchers, or maybe extensionists.

Finally, the **Hi-sAFe** development team organised several trainings over the past few years and training material has been created (e.g. recording of the training sessions, powerpoint presentations, practicals etc…). This material is available upon request to the **Hi-sAFe** development team and will be published on the website once the model is made open access (see section 3.1.2).

3.1.3 INTEROPERABILITY

The model is programmed in Java, using text files as inputs and can be run either through user interface of Capsis or in batch mode (launched from a command line). It produces csv files as outputs. It should be noted that we developed an R package to prepare simulations, run them and analyse the results. In this sense, **Hi-sAFe** is interoperable with any R-compatible program. However, **Hi-sAFe** is a very detailed model, which takes into account a large number of processes and produces a huge amount of output variables. The downside of this complexity is that the computational time is also large: one simulation of the 50-year long life of a system typically takes 1-2 hours to run, making the model unsuitable for interoperability with applications that need real-time or near-real time answers, such as tools for ex ante evaluation during system design.

Our approach to overcome this problem is to apply machine learning techniques to build a meta-model of the **Hi-sAFe** model, to be able to make quick evaluations of different systems in different pedoclimatic and management conditions. For this, we need to build the training dataset, so that it covers the desired range of cropping system, tree configuration, soil, climate, management, etc… and run the full model to produce relevant output variables (crop and tree yield, components of the water and nitrogen balance). Then it will be necessary to choose a suitable machine learning technique and train the meta-model on the simulated data. Finally, the meta-model should be made available for queries through an API, for coupling with existing or new applications developed by partners of the DigitAF project.

3.1.4 REUSABILITY

The code will be published under a GPL licence, meaning it can be re-used for any non-commercial application. As part of the documentation effort planned in the framework of the DigitAF project, the source code will also be reviewed in order to add all the necessary comments for its understanding.

Hi-sAFe is embedded into the Capsis platform, a platform developed to facilitate exchange of modules within models hosted on the platform (it can be noted that **Hi-sAFe** itself uses modules that were developed in other models, for example the light interception module). However, both Capsis and **Hi-sAFe** are written in JAVA and use the inheritance process of object-oriented languages. Therefore **Hi-sAFe** modules are not reusable as stand-alone modules. This is an obstacle to the reuse of **Hi-sAFe** source code outside of the Capsis platform.

Further improvement of the model through collaborative approaches will be made possible thanks to the github repository (https://github.com/hisafe).

3.2 Tree selection tools

Tree species selection is an important step in agroforestry system design, and it was highlighted in several of the Living Labs as a priority for tool development. Several tree selection tools have been developed independently by several teams in research institutes, technical institutes or even private companies. These include:

- **DENTRO** by ILVO (https://bdbnet.bdb.be/pls/apex/f?p=147:11)
- **ShadeTree Advice** by CIRAD (https://www.shadetreeadvice.org/)
- **Deciduous** by GRAB
- **SCSM** by RegenFarmer (https://regenfarmer.com/agroforestry-planning-software/)

This diversity of tools can create confusion for practitioners because they could be unaware of the existence of a tool adapted to their situation. Furthermore, no effort has been made to homogenize the look and feel of these tools, nor to compare the underlying models and data behind each tool to increase robustness of advice.

In DigitAF, our objectives are to:

- Identify existing tree selection tools
- Get access to the code and the database of each tool
- Find a common framework to organize the data, with a hierarchy of criteria so that each tool can fit, whatever its specific focus
- Reformat the data of each tool into the common format and join the databases thus improving reusability
- If possible (e.g. if there is overlap between the different tools in terms of species and pedo-climatic conditions), compare the results of the different tools
- Develop a unified tool based on this common database (thus improving de facto the interoperability of tools), or combine the different tools in one entry point giving access to each of the tools, to improve findability of tools
- Develop API infrastructure to allow querying the tools through API REST requests, to allow interoperability with existing or future apps.

An important ambition of this work is to participate in the definition of necessary standards, IT architecture and code sharing opportunities for the interoperability of tree selection tools, not only among the DigitAF partners, but also beyond the project consortium. Therefore we will open the discussions to all parties interested in joining forces for tree species selection tools in agroforestry. Currently, 11 teams are interested in this joint effort: INRAE ABsys (CIRAD and INRAE, France), AMAP (CIRAD and INRAE, France), ILVO (Belgium), GRAB (France), RegenFarmer (Denmark), EFI (Finland), Agroscope (Switzerland), Louis Bolk Institute (The Netherlands), WUR (The Netherlands), Landfiles (France), FarmTree (The Netherlands). The last three teams are part of the ReForest or Agromix European projects.

A specific working document has been set up in a shared space to allow collaboration between partners within and beyond DigitAF, as well as a dedicated repository on github (https://github.com/euraf/agroforestreeadvice).

3.3 Combinatorial maps as a common standard for describing agroforestry systems

A recent publications has defined the concept of Ecosystem Service Spatial Unit (Rafflegeau et al. 2023) as a highly relevant concept for the design, management and modelling of agroforestry systems. Even more recently, this concept has been implemented digitally using combinatorial maps, with the ambition to use this data format as a single format to translate to and from all other representations of agroforestry systems (Lemière et al. 2023), thus paving the way to the interoperability of agroforestry tools. However this work is not yet complete and further work will be needed to integrate this representation into agroforestry system design tools.

In order to facilitate this process, we will use the OneForest Knowledge Base that is being developed in the HE associated project *eco2adapt* (https://www.eco2adapt.eu) also coordinated by INRAE. This FAIRification framework combines ontologies such as SOSA, OWL Time and GeoSPARQL and an alpha version is available:

https://purl.org/oneforestkb/LivingLabMapDiscovery

The initial semantic model (or profile) has been defined and stabilised using example datasets from French Guiana forests. We will focus on providing knowledge on ecosystem services in different agroforest plots, depending on species and management practice. We will use the work performed in the original AOBRA Knowledge base, as a foundation for defining agroforestry-specific ontologies in the OneForest Knowledge base.

The knowledge model defined is intended to be as generic and reusable as possible, and is therefore based on Semantic Web data standards and proven high-level semantic components. To include knowledge in the knowledge base, partners must protect any data sets (for example with DOIs in a repository) and then forward data sets to A. Stokes (INRAE). Ultimately this semantic technology will link to the United Nations (UN) Data Hub, so policy-makers can access agroforestry and ecosystem service data in near-real time.

We then plan to apply this architecture to integrate the modules developed in DigitAF (e.g. those presented in sections **Erreur ! Source du renvoi introuvable.**, 2.5 and 3.1.4) within the augmented reality tool presented in section 2.3.

3.4 Improving the site-specific parameterization (reusability) of tools

UEX will facilitate site-specific parametrization, by using remote sensing to assess tree-crop performance, using models that can cope with two-layered systems, such as **SCOPE** (Soil-Canopy Observation of Photosynthesis and Energy fluxes).

Remote sensing tools are increasingly used to provide extensively and timely information at large spatial and temporal scales of agricultural systems. However, remotely sensed products cannot provide information on the mechanisms of growth, development and yield of crops and more importantly of complex systems were several vegetation layers are combined, such as in agroforestry. The combination of remotely sensed products with processes based models can overcome this limitation by means of data assimilation routines. Models can simulate mechanistically growth, whereas remotely sensed data provides large temporal and spatial information through observations and inversions, complementing each other. UEX will facilitate the process of data assimilation by providing remotely sensed products. UEX is evaluating the suitability of the **SCOPE** model to provide this information. One limitation of **SCOPE** is that it does not distinguish between vegetation layers, it provides information at the canopy level, therefore it is only useful at the system level. The proposed plan is to evaluate the suitability of **SCOPE** and provide alternative sources of remotely sensed information to optimize tree-crop performance.

GRAB will develop the predictive tool **DEXIAF** (developed in France since 2015) under 2 EU Living labs within the DigitAF project. **DEXIAF** aims at better assessing the sustainability of a new agroforestry plot, considering economic, social and environmental dimensions. It is gathering expert knowledge through qualitative (so called fuzzy logic) modeling, in order to hierarchize and weigh the most determining criteria for a successful agroforestry project. Under DigitAF, 2 LL experiences will be used to compare their AF experience and results with **DEXIAF** prediction data.

GRAB will also display the **DECIDUOUS** tool in several partners' countries interested (Belgium, Switzerland, UK, Czech Rep, Germany identified so far). **DECIDUOUS** aims at choosing the most relevant fruit species, then rootstocks, then cultivars for a given plot, considering edaphic and socio-economic constraints for the farmer. It is currently being finalized for France and will be made available for EU countries from 2024.

3.5 Improving the usability of tools

Test of the tools in the Living Labs is underway (first semester of 2024). The test sessions start with a demonstration of a tool, followed by an "exercise" where the users are asked to perform a given task with the tool. Finally the stakeholders's feedbacks are collected with a standardized method allowing stakeholders to rate each tool on two dimensions: usefulness and usability of a tool (see Figure 5). This rating is completed by a short questionnaire to get feedback about which aspects of the app could be improved, and what is missing for the app to be able to solve the user's problems. Results from these test sessions will allow us to improve further the content and the user interface of our tools.

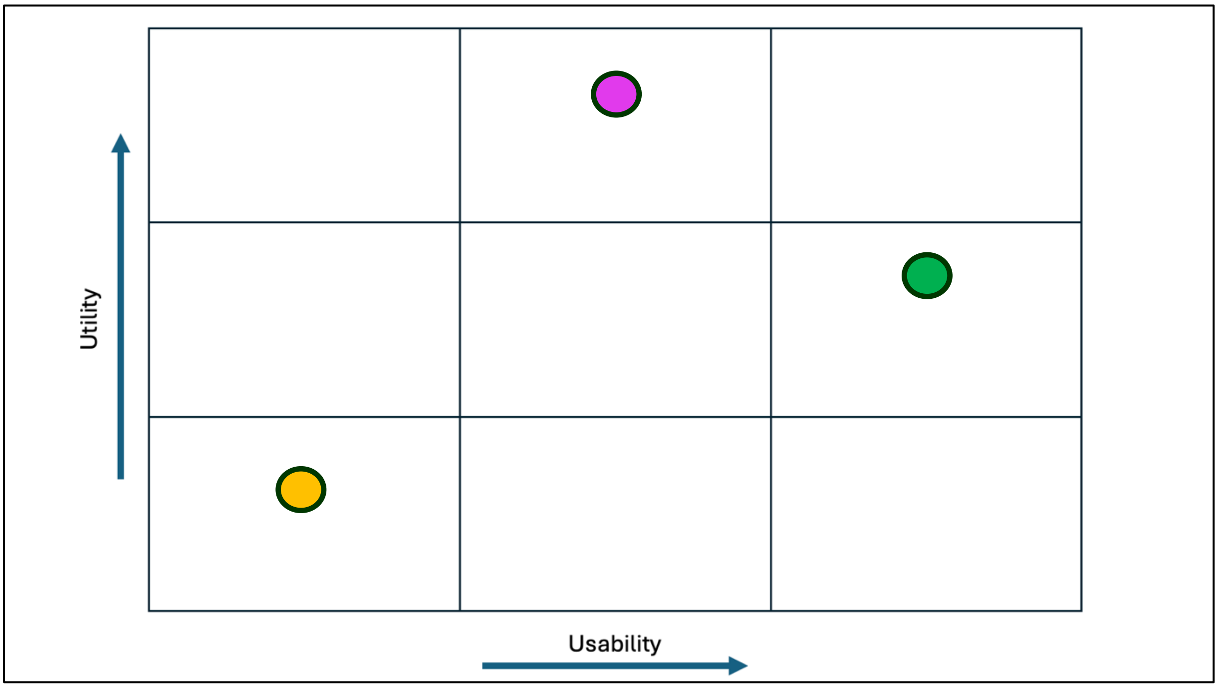

Figure 5: example of result of the evaluation of three tools by an Italian farmers

4 Summary of activities

Table 1: summary of activities performed/to be performed on the different tools/models as of June 2024. Tools that are not in bold don't have a name yet.

Model	Improvements	Partners involved	Expected completion time
Hi-sAFe	CO2 effect Cavitation (comparing with **SUREAU**) Making the code open-source	INRAE, ILVO	Done August 2024 Dec 2024
WaNulCas	Comparison with **Hi-sAFe**	INRAE	Done
AgroforestAR	Developing prototype	INRAE, CIRAD	Sept 2024
Pest modeling	Model based on microclimate Model based on BRN • Build GUI • Parameterize new contexts	INRAE	 July 2024 June 2025
Tree management	Inventory of tools Advisor survey analysis framework of local issues and resources for tree management Educational material for tree management	CIRAD	Done Done August 2024 August 2024
DENTRO	Launch Dentro as a separate tool in “Agroforestry Planner” + Add extra modules (fruit and nut tree species & variety choice, Poplar cultivar choice).	ILVO	June 2025
Dutch factsheet on tree species choice in a changing climate	Translation to English	ILVO	October 2024
SCOPE	Provide site-specific parameters based on remotely sense products and processed by SCOPE model and assess the suitability to provide information for the optimization of tree-crop performance	UEx	June 2025
ShadeTreeAdvice	Cleaning of data Inserting into AFTA	CIRAD	Done Done
AgroforesTreeAdvice	Development of GUI Insertion of existing tools • **ShadeTreeAdvice** • **DENTRO** • **DECIDUOUS** • **SCSM** • Czech database • **JBOJP** Development of API Consolidation of data	INRAE	Done Done Done Done Done Done Sept 2024 Jan 2025 June 2025
OneForest+combinatorial maps	Integration of spatial design tools (combining trees and crops) and production of ecosystem service maps	INRAE	June 2026
DEXIAF	Testing the tool with mature AF plots	INRAE, GRAB, Unilasalle	End of 2024
DECIDUOUS	Parametrization for France Translation into English Adaptation to other conditions	GRAB, INRAE, RMT Agroforesteries	Achieved Early 2025 End of 2025

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6 References

Carevic FS, Fernández M, Alejano R, et al (2010) Plant water relations and edaphoclimatic conditions affecting acorn production in a holm oak (Quercus ilex L. ssp. ballota) open woodland. Agrofor Syst 78:299–308. https://doi.org/10.1007/s10457-009-9245-7

Cochard H, Pimont F, Ruffault J, Martin-StPaul N (2021) SurEau: a mechanistic model of plant water relations under extreme drought. Ann For Sci 78:55. https://doi.org/10.1007/s13595-021-01067-y

Dupraz C, Blitz-Frayret C, Lecomte I, et al (2018) Influence of latitude on the light availability for intercrops in an agroforestry alley-cropping system. Agrofor Syst 92:1019–1033. https://doi.org/10.1007/s10457-018-0214-x

Dupraz C, Wolz KJ, Lecomte I, et al (2019) **Hi-sAFe**: A 3D Agroforestry Model for Integrating Dynamic Tree–Crop Interactions. Sustainability 11:2293. https://doi.org/10.3390/su11082293

Forner A, Morán-López T, Flores-Rentería D, et al (2020) Fragmentation reduces severe drought impacts on tree functioning in holm oak forests. Environ Exp Bot 173:104001. https://doi.org/10.1016/j.envexpbot.2020.104001

Fremout T, Gutiérrez-Miranda CE, Briers S, et al (2021) The value of local ecological knowledge to guide tree species selection in tropical dry forest restoration. Restor Ecol 29:e13347. https://doi.org/10.1111/rec.13347

Huo G, Gosme M, Gao X, et al (2021) Dynamics of interspecific water relationship in vertical and horizontal dimensions under a dryland apple-Brassica intercropping system: Quantifying by experiments and the 3D **Hi-sAFe** model. Agric For Meteorol 310:108620. https://doi.org/10.1016/j.agrformet.2021.108620

Joffre R, Rambal S, Ratte JP (1999) [No title found]. Agrofor Syst 45:57–79. https://doi.org/10.1023/A:1006259402496

Lemière L (2023) La réalité augmentée pour faciliter la conception de systèmes agroforestiers. PhD Thesis, Institut Agro Montpellier Supagro

Lemière L, Jaeger M, Gosme M, Subsol G (2023) Combinatorial maps, a new framework to model agroforestry systems. Plant Phenomics under review:

Natalini F, Alejano R, Vázquez-Piqué J, et al (2016) The role of climate change in the widespread mortality of holm oak in open woodlands of Southwestern Spain. Dendrochronologia 38:51–60. https://doi.org/10.1016/j.dendro.2016.03.003

Rafflegeau S, Gosme M, Barkaoui K, et al (2023) The ESSU concept for designing, modeling and auditing ecosystem service provision in intercropping and agroforestry systems. A review. Agron Sustain Dev 43:43. https://doi.org/10.1007/s13593-023-00894-9

Reyes F, Gosme M, Wolz KJ, et al (2021) Alley Cropping Mitigates the Impacts of Climate Change on a Wheat Crop in a Mediterranean Environment: A Biophysical Model-Based Assessment. Agriculture 11:356. https://doi.org/10.3390/agriculture11040356

Rigal C, Wagner S, Nguyen MP, et al (2022) SHADETREEADVICE methodology: Guiding tree-species selection using local knowledge. People Nat pan3.10374. https://doi.org/10.1002/pan3.10374

Rolo V, Moreno G (2019) Shrub encroachment and climate change increase the exposure to drought of Mediterranean wood-pastures. Sci Total Environ 660:550–558. https://doi.org/10.1016/j.scitotenv.2019.01.029

Sinoquet H, Le Roux X, Adam B, et al (2001) RATP: a model for simulating the spatial distribution of radiation absorption, transpiration and photosynthesis within canopies: application to an isolated tree crown. Plant Cell Environ 24:395–406. https://doi.org/10.1046/j.1365-3040.2001.00694.x

Talbot G, Dupraz C (2012) Simple models for light competition within agroforestry discontinuous tree stands: are leaf clumpiness and light interception by woody parts relevant factors? Agrofor Syst 84:101–116. https://doi.org/10.1007/s10457-011-9418-z

Van Der Wolf J, Jassogne L, Gram G, Vaast P (2019) TURNING LOCAL KNOWLEDGE ON AGROFORESTRY INTO AN ONLINE DECISION-SUPPORT TOOL FOR TREE SELECTION IN SMALLHOLDERS' FARMS. Exp Agric 55:50–66. https://doi.org/10.1017/S001447971600017X