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# Modeling of vine agronomic practices in the context of climate change

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**Abstract.** Global climate change affects regional climates and hold implications for viticulture worldwide. Many studies have addressed the issue of the impact of climate change on viticulture in most wine regions worldwide, yet few studies are devoted to observing and simulating both climate and climate change at the "terroir" scale (local scale). However, phenological variations as well as differences in grapes/wine quality are often observed over short distances in a wine-region, which are related to local characteristics (slope, soil, seasonal climate . . . ). This paper proposes a modeling approach to simulate behavior changes in wine grower activities and to analyze the impact of changing strategies in wine production. Two experiments were conducted in the small wine appellation grand cru Quart de Chaume (Coteaux du Layon, Loire Valley, France) and in the wine estate in Mendoza (Bodega Alta Vista) where all of the methodology (from the implementation of the knowledge database to the analysis of the first simulation) is presented. Given that this prototype is still under development, several research perspectives are discussed.

## INTRODUCTION

Global climate change affects regional climates and hold implications for viticulture worldwide. Many studies have addressed the issue of the impact of climate change on viticulture in most wine regions worldwide, yet few studies are devoted to observing and simulating both climate and climate change at the "terroir" scale (local scale). However, phenological variations as well as difference in grapes/wine quality are often observed over short distances in a wine-region, which are related to local characteristics (slope, soil, seasonal climate . . . ).

A wide range of the adaptation solutions suggested to reduce the impacts of climate change on viticulture have resulted from studies carried out at regional scales using computer simulations. However, results from models hold significant uncertainties e.g. difficulty to predict future climate due to uncertainties related to emissions scenarios as well as model parameterizations and integrations and, finally, regional scales are not the most appropriate scale for winegrowers. Climate variability at local scales explains more clearly the characteristics of wines, and winemakers have always been adapting their practices based on it. In the context of climate change, the development in knowledge of climate and impacts on grapevine performance and resulting wine characteristics allow to identify methods of adaption to climate change based on constant evolution of practices rather than on radical change of practices such as shifting of viticultural regions or change of cultivars.

The aim of this contribution is to conceptualize a generic model (a site specific viticultural activity) including strategies of production (modeling by decision trees) to reproduce the impact of spatial and temporal variability of climatic conditions on grapevine growth and berry maturity using an approach that combines technologies derived from GIS, agent-based models and spatial and temporal databases. The objective is to specify a systemic and integrated modeling environment for simulating grapevine growth and berry ripening under different conditions and constraints (slope, aspect, soil type, climate variability . . . ) and to integrate production strategies and corresponding adaptation rules according to the evolution of these constraints.

## 1. Modeling approach

The approach aimed to link in situ observation about phenology and agronomic action (Bonnefoy et al., 2009) to issues in terms of seeking optimal vine adaptation to wine-producing soils' specificity (Barbeau et al., 2001; Asselin et al., 2003). It draws on the DAHU multi-agent simulator.

The DAHU platform provides a simulation environment that can integrate multi-source and multi-scale spatiotemporal constraints as forcing variables within constrained agent models (Fig. 1).

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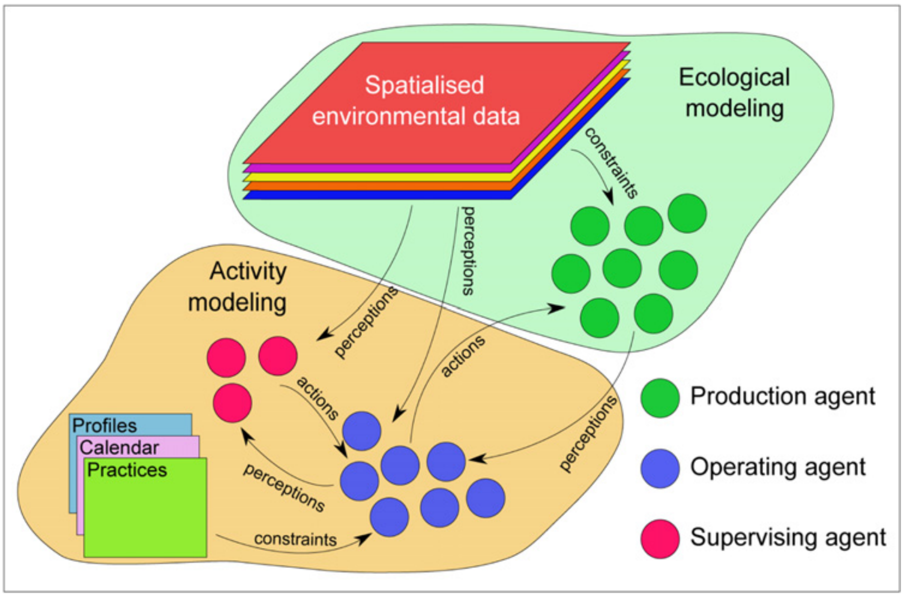


**Figure 1.** The DAHU simulation platform.

spatiotemporal constraints as forcing variables within constrained agent models (Fig. 1). This approach meets the requirement of explicitly formalising spatiotemporal relationships between spatial entities, environmental processes and human activities. The aim is to set up a methodological framework that can run without a complete system specification, i.e. considering the modelling environment as the result of a set of heterogeneous constraints in scalar terms.

This approach meets the requirement of explicitly formalising spatiotemporal relationships between spatial entities, environmental processes and human activities. The aim is to set up a methodological framework that can run without a complete system specification, i.e. considering the modelling environment as the result of a set of heterogeneous constraints in scalar terms. The specificity of the DAHU platform is that the entire model is based on the technical description of human activities (activity modeling in Fig. 1). Each activity is modelized by an agent[1].

Agents are selected based on the detailed typology of the various activities and their associated practices (Le Tixerant et *al.*, 2012; Tissot *et al.*, 2004). In the DAHU platform, the environment consists of a set of spatialised data. In particular, it includes constraints that influence the development of an activity. These constraints directly or indirectly influence the decisions and/or actions of agents.

### 1.1. Formalisation of agents

The integration of this model in the DAHU simulator aimed to optimise the connections between the supervising, operating and production agents.

– the "Supervisor" Agent plays a supervising role in the model. It sets the specifications of the various wine designations and imposes specific production methods. It is directlyrelated to the "WineGrowers" Agents who provide information regarding the quality of grapes produced by their vines. According to this information, the "Supervisor" agent may modify wine specifications;

– "Viticulteurs" Agents aim to produce wine that meets precise specifications according to the target designation. This action involves growing the grapevine in optimal conditions given the agronomic specificities of the grapevine-grower's plots;

– "Vignes" Agents are grape production entities. They generally represent a plot or an entity deemed homogeneous in terms of agronomic features (definition based on soil units; Bodin et al., 2006). The role of these agents is to reproduce vine growth dynamics according to climate conditions.

The relationships between these three types of agents determine the production strategies adopted by the grapevine growers. The Operating Agent group was thereby enhanced with decision-making regulations established based on regulations applied under climate constraints.

### 1.2. Modeling sequence

In order to relate vine management to environmental constraints, a significant knowledge base informing all biophysical and agronomic parameters of the vine as been developed. This database allows simulating the growth cycle of the vine by taking into account climate variability and agronomic practices.

In order to model the growth of the vine simple algorithms based on bioclimatic indices are used. Theses indices allows to study plant response to climate variability according to grape variety (Morlat, 2010; Tonietto 2004; Huglin, 1986).

Temperature data are also used to calculate Huglin solar thermal index (Huglin, 1978), which is used by the

[1] An agent is an entity capable of acting on itself or its environment, which reacts to its changes and has a partial representation of its environment (Wooldridge, M. 2009).

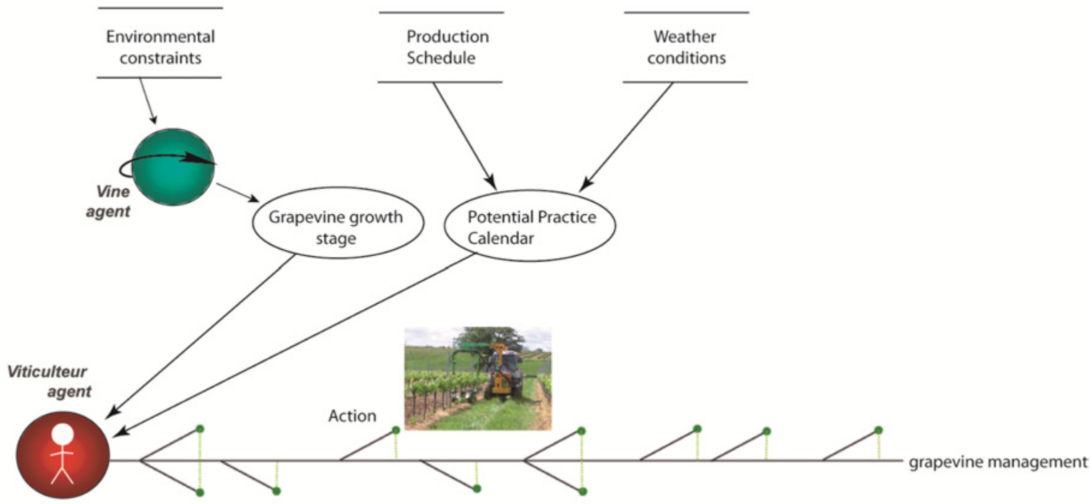


**Figure 2.** Modelling vine management in the context of climate change.

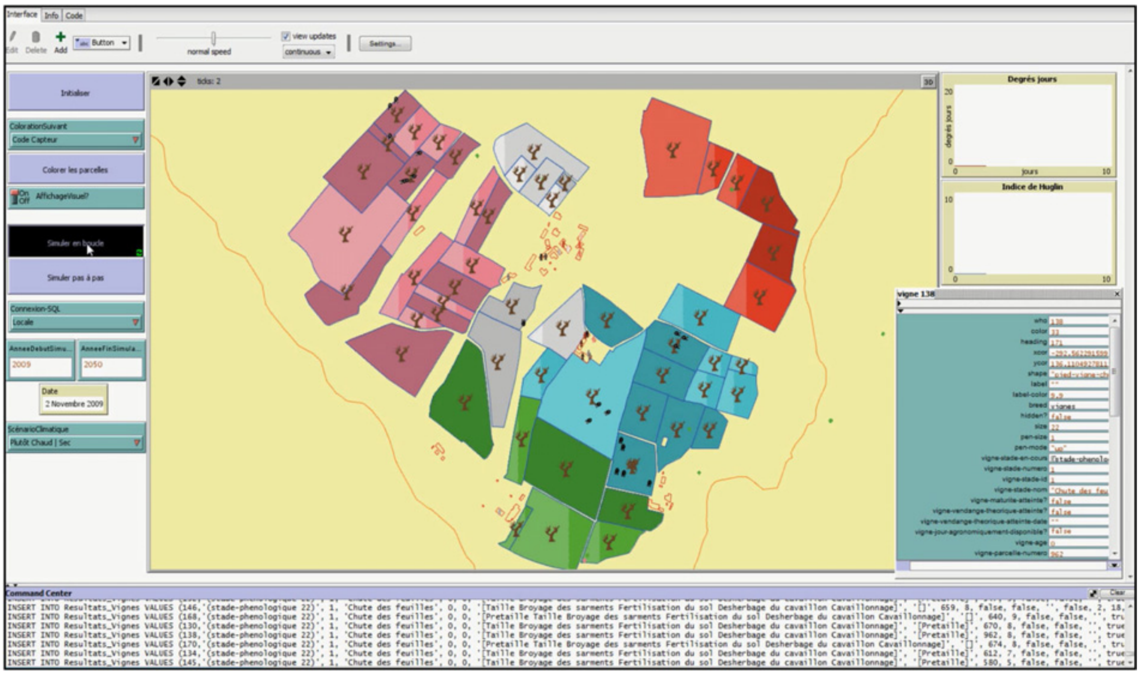

**Figure 3.** Screen capture of DAHU-Vigne model.

model to determine the potential harvest date (the start of the harvest depends on the decision of the winemaker).

The value of the Index Huglin for a station is the cumulative value of the index at the date of September 30, the accumulation start since April 1 (northern hemisphere to the southern hemisphere, index is calculated for the period from September 30 to April 1) using the following formula:

$$IH = \Sigma[(Tm - 10) + (Tx - 10)/2] * k$$

where Tm = average temperature,

Tx = maximum temperature

and k = coefficient of day length ranging from 1.02 to 1.06 (depending on the latitude of the area of interest).

The architecture of the model is to formalize a relationship between vine growth cycle, grape variety and production method used.

The aim of the simulations (the model is under development) is to relate grapevine phenological stages to climate conditions and crop management methods in a context of global change (Fig. 2). The choice of agronomic actions also depends on the production strategy winemaker. All these elements determine agronomic practices that are adjusted in real time in the model. Therefore the actions taken at time step t can influence the choices made at t + n.

## 2. Simulation

The purpose of the first tests carried out in the Coteaux du Layon region (France) is to assess the capacity of grapevine growers to adapt to the considerable rise in temperature and produce sweet wine

(Bonnefoy *et al.*, 2009). Three production profiles were identified: conventional (traditional vine-growing), integrated (plant protection product and fertiliser restrictions), organic (precise specifications severely limiting the use of plant protection products). An extensive survey of grapevine growers helped associate calendars of specific practices with each production profile. These calendars facilitated the development of decision trees under agro-climatic constraints. Temperature and precipitation data were used to define which days were agronomically feasible for carrying out vineyard practices. According to these data, the production profile and the agro-climate features (type of soil, slope, orientation), each WineGrowers Agent makes crop management choices.

In Argentina the Bodega AltaVista prototype is devoted to assess the control of plant water stress by optimising agronomic action and the use of irrigation in Mendoza country. The bodega has greatly contributed to the development of this model by providing bioclimatic data and information on agricultural practices The set of parameters and all the agronomic action can be controlled via the GUI model. The NetLogo platform used to support the development provide visualization tools such as maps and graphics probes. Agents choices and actions can be viewed at each time step, at daily scale for the prototype actually developed (Fig. 7). Probes are also used to visualize graphically many parameters as bioclimatic indexes for example.

GUI model is used to display relevant results and to interact with winemakers. However it is difficult to draw specific conclusions about the data without further analysis. This first stage, currently being tested, requires validation because decision-making is a complex chain of relationships to model. Two methods are currently under development. The first method focuses on adapting the production strategy from a knowledge base consulted by the Viticulteur Agent at each time step. The second, more complex method draws on iterative stochastic algorithms to estimate of the best grapevine management solution.

## 3. Conclusion

The modeling approach presented in this chapter offers a comprehensive approach to simulate the interactions between viticulture and environmental constraints. Through the development of a multi-agent model the issue of the impact of climate variability on agronomic practices and production strategies are specifically targeted. DAHU modeling platform allows simulation of vine growth from bioclimatic indices and secondly simulation of agronomic practices in the context of climate change. This step is crucial for the analysis of production strategies.

After this first development step many prospects are considered. They relate mainly to improvements in computer code of DAHU-Vine.

That needs to be expanded to assess the implications of agronomic actions on the dynamics of the vine. From a technical point of view it will be necessary to introduce feedback loops within the model to simulate the consequences of some agronomic choices on vine characteristics (vigor, earliness, resistance to pathogens . . . ). Cooperation with vine-growers also raise the issue of ownership of such a modeling approach in a context where the skills and experience are the best tools to adapt to changing climate conditions. Discussions with wine-growers are essential to validate and improve the model and also to build tangible scenarios of practical adaptation to climate change. In this context the work sessions are planned to construct co-scripted and prospective simulations.

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