SIMULATING THE IMPACT OF CLIMATE CHANGE ON GRAPEVINE BEHAVIOUR AND VITICULTURAL ACTIVITIES

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Abstract:

Context and purpose of the study- Global climate change affects regional climates and hold implications for wine growing regions worldwide (Jones, 2007 and 2015; Van Leeuwen and Darriet, 2016). The prospect of 21st century climate change consequently is one of the major challenges facing the wine industry (Keller, 2010). They vary from short-term impacts on wine quality and style, to long-term issues such as varietal suitability and the economic sustainability of traditional wine growing regions (Schultz and Jones 2010 ; Quénol 2014). Within the context of a global changing climate, most studies that address future impacts and potential adaptation strategies are largely based on modelling technologies. However, very few studies model the complex interaction between environmental features, plant behaviour and farming activities at local scales. In viticulture, this level of assessment is of particular importance, as it is the scale where adaptation matters the most. Within this context, it seems appropriate to develop a modelling approach, able to simulate the impact of environmental conditions and constraints on vine behaviour and the dynamics of viticultural activities.

Material and methods - Our modeling approach, named SEVE (Simulating Environmental impacts on Viticultural Ecosystems), has been designed to describe viticultural practices with responsive agents constrained by exogenous variables (biophysical, socio-economic and regulatory constraints). Based on multi-agent paradigm, SEVE has two principle objectives, first, to simulate grapevine phenology and grape ripening according to climate variability and secondly, to simulate viticultural practices and adaptation strategies under environmental, economic and socio-technical constraints. Each activity is represented by an autonomous agent able to react and adapt its reaction to the variability of environmental constraints. The reaction chain results from a combination of natural and anthropogenic stresses integrated at different scale level (from plot to vineyard).

Results - Simulation results underline that small scale variability is strongly linked with vine phenology stages and ripeness potential. Over the next century, winegrowers will likely be confronted by increasing temperatures and changing rainfall patterns that will have important impacts on agronomic itineraries and adaptation strategies. Through different experiment in european vineyards in the context of ADVICLIM project (http://www.adviclim.eu/), SEVE model provide prospective simulation of potential adaptation strategies from short-term (e.g. in harvest management practices) to long-term adjustment, such as in varietal selection. In response to increasing temperatures and changing rainfall patterns, they vary therefore in nature and effectiveness, where longterm measures in the choice in grapevine variety and the use of irrigation seem to be the most effective.
Keywords: grapevine, production strategies, climate change, multi-agents model, adaptation, temporal dynamics, spatial variability, wine growers

1. Introduction

In the field of viticulture, model developments mainly concerns agronomic processes such as plant/soil relationship (De Cortazar-Atauri, 2006, Moriondo et al., 2015), plant disease management (Atallah, 2014) or bio-economic approach for sustainable development of viticulture (Lescot et al., 2014). By providing a transdisciplinary paradigm Agent's Based Model are particularly adapted tools for simulating complex interactions between ecological and social components (Paget 2016). Traditionally used for simulate natural resources management (Le Page *et al.*, 2013), ABM showed a good ability to address issues related to the adaptation of human activities to environmental change (Tissot 2018). Usually agents interact with an environment that creates some constraints or opportunities. In the context of viticulture the difficulty is to manage agronomic processes and the dynamic interactions between vine and winegrowers which leads to management strategies. To reach this objective, our method took a cross-cutting approach focused on combining a multi-agent model with multi-scale spatio-temporal databases.

In the context of current and future environmental impacts on viticultural ecosystem, this approach has two principle objectives:

- simulate vine phenology and grape ripening under spatial and temporal environmental conditions and constraints
- simulate viticultural practices and adaptation strategies under various constraints (environmental, economical, socio-technical)

The proposed modelling approach aims to link environmental and agronomic observations with the need to optimize farming strategies at plot scales (Barbeau *et al.*, 2001 ; Asselin *et al.*, 2003). To address all the factors leading to viticultural management we have chosen to implement an agent based model focus on simulating agronomic practices and production strategies depending on environmental conditions (vine phenology, water balance and water stress, business structure, end-product objectives…).

2. Material and methods

SEVE (Simulating Environmental impacts on Viticultural Ecosystems) model has been designed to describe viticultural practices with responsive agents constrained by exogenous variables (biophysical, socio-economic and regulatory constraints). Each activity is represented by an autonomous agent able to react and adapt its reaction to the variability of environmental constraints:

- "Supervisor" Agents - imposes specific production regulations on winegrowers
- "Winegrower" Agents - grow grapes and produces wine
- "Vine" Agents - represent the vineyard plots

The behavioural relationship between these three types of agents determine the production strategies adopted by the "Winegrower" agents. The simulation framework of the model is broken down into four thematic groups. The first is focused on modelling the phenological cycle of the grapevine. The second includes specific elements related to the vineyard management structures. The third integrates all the climatic characteristics of the simulated vineyards. And lastly, the fourth thematic group is dedicated to the simulation of the grapevine pests and diseases.

To perform the integration of spatio-temporal data, the SEVE model is coupled with a spatio-temporal database (Postgres/PostGIS server). Spatio-temporal data are integrated as individual or combined constraints on agent behaviour. In return, each agent is endowed with responsive capacities expressed through behaviour that changes according to environmental evolution. SEVE model mobilizes therefore an important knowledge base informing all biophysical and agronomic parameters of the grapevine. This database allows simulating grapevine phenology under environmental constraints and viticultural practices executed by the "Winegrower" agents. The "Vine" agent has many attributes related to the characteristics of the production plots (soil water reserves, slope index, soil specificity, ...). This agent following phenological stages during its growth cycle and reacts to climatic variability, and other disturbances (e.g. fungal diseases).

Management practices and decision-making process are based on decision trees. These decision trees allow to determine an agronomic itinerary for each vineyard plot according to the climatic profile of the year and the winegrower's production strategies. The agronomic itinerary can integrate general agronomic actions (e.g. winter pruning, trimming,...) but also adaptation responses to climate constraints (soil tillage, weed maintenance ...). Therefore, the choice of an agronomic action or an adaptation tool is not only determined by grapevine behaviour or climate variability, but it also is strongly dependent on production strategies, which vary among winegrowers based on their business structure (e.g. family owned, or private, farm size, etc.),

3. Results and discussion

As part of the LIFE-ADVICLIM project, the SEVE model has been implemented in various European vineyards in France, Germany, England and Romania.
For each site, retrospective and prospective simulations were carried out. The first results show that SEVE model is able to reproduce the behavioural dynamics of grape growing and viticultural practices according to climate variability. This variability directly affects agronomic practices, which can be more or less numerous, both over time and space. In hot and dry climate contexts, shallow soil tillage activities will be used to limit grapevine water stress, especially in vineyard plots with low water holding capacities. In normal to wet growing seasons, inter-cropping management practices will be used to manage grapevine vigor and yield, especially in deep soils with high water holding capacities. The use of pesticides is less correlated to the global profile of the growing season, as it depends on the season distribution of temperatures, humidity and especially rainfall (i.e. both amount and intensity). If these elements are highly correlated with grapevine phenological properties, winegrower's individual strategies can completely change the choice of an action or a specific tool. For example the use of pesticides can vary depending on the production profile. In organic production, the use of contact products requires a high spray frequency during periods of an increased risks of pathogenic diseases and frequent rainfall (a few days between each spay). In conventional production, by using systemic product, wine growers reduce significantly this frequency (usually 14 days between spraying).

For prospective simulation, the regional climate projections of two Representative Concentration Pathways (i.e. RCP 4.5 and 8.5) has been integrated as forcing data. Depending on the chosen climate scenario, the results show an important temporal variability and shift in the grapevine phenological cycle (Figure 13). These results are representative of the increase in seasonal temperatures that will significantly affect the timing of grapevine earliness and the ripeness level of grapes. Adaptation strategies are strongly linked with this seasonal shift but also depend on local constraints related to the specificity of vineyards.
Although the results are different for each pilot site, general trends can be highlighted. In the short term, adaptations can be made in terms of harvest, soil and vigour management practices. While in the medium to long term, changes could occur in the choice of plant material (delay the phenological cycle and avoid a very early maturity) the use of tools to control water stress (e.g. mulching techniques or irrigation) or to limit the effect of extreme temperature (e.g. shading systems).

4. Conclusions

The main goal of our approach was to provide information about the spatial and temporal challenges for viticulture to adapt to climate change. SEVE model shows that vine sensitivity to climate change varies at fine scale depending on environmental constraints (topography, soil type, climate variability…).
By providing spatial and temporal information about numerous control parameters SEVE simulate the evolution of vineyard's agronomic characteristics and provide prospective wine grower's work schedule associated with production profile (conventional, integrated and organic) and climate change scenario.

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