Co-design and evaluation of spatially explicit strategies of adaptation to climate change in a Mediterranean vineyard watershed

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Abstract

Climate change challenges differently wine growing systems, depending on their biophysical, sociological, and economic features. There is a need to locally design and evaluate adaptation strategies combining several technical options and considering local opportunities and constraints. The case study was a Mediterranean vineyard (1,500 ha) in Southern France. We organized five workshops, with in-between modelling phases to (1) design spatially explicit adaptation strategies with stakeholders, (2) numerically evaluate their effects on phenology, yield and irrigation needs under future climatic conditions, and (3) collectively discuss simulation results. A process-based model was developed to evaluate the effects of six technical options (late varieties, irrigation, reduced canopy, cover cropping, reduced density, shading), and vineyard relocation. We co-designed three adaptation strategies. *Delay harvest strategy* with late varieties showed little effects on decreasing air temperature during ripening. *Water constraint limitation strategy* would compensate for production losses if long-term adaptations were adopted, and more land got access to irrigation. *Relocation strategy* would foster high premium wine production in the mountainous areas where grapevine is less impacted by climate change. This research shows that a spatial distribution of technical changes allows adaptation to climate change, and that the collaboration with stakeholders is key to identify relevant adaptations.

Introduction

Mediterranean viticulture is a cultural and economic emblem that is particularly threatened by climate change: advancement of the phenological cycle, decrease in yields and harvest quality (Ollat & Touzard, 2014). To limit these adverse effects, it is necessary to combine adaptation levers in several areas of crop and soil management. However, the scientific and professional communities are struggling to provide clear recommendations on the strategies to be implemented to articulate these levers at a local scale. A systematic literature review highlighted two main limitations that scientists and stakeholders face for designing and evaluating climate change adaptation strategies in the grapevine sector (Naulleau et al., 2021). First, quantitative methods based on simulations at large spatial scales (e.g Fraga et al., 2012; Morales-Castilla et al., 2020) have difficulties to consider the heterogeneity of pedoclimatic and socio-economic contexts, that mainly determine the levels of vulnerability and adaptive capacity of wine-growing systems. Second, studies based on participatory approaches (e.g. Lereboullet et al., 2013; Neethling et al., 2017) manage to better capture this spatial diversity and identify relevant adaptations but they do not allow to quantitatively evaluate their performance. The present study aimed at building and quantitatively evaluating adaptation strategies, defined as combinations of adaptation levers in time and space, which make sense locally. We developed and implemented a method combining a participatory approach with an *ad hoc* quantitative modelling approach in a Mediterranean watershed. The study provides some important insights into multi-scale evaluation and joint work between modellers and stakeholders.

Materials and methods

The study took place in the Rieutort watershed that is dominated by grapevine production (1,500 ha of vineyards, 80% of the agricultural area) and is located in the South of France (Figure 1). Three main types of grapevine production systems are encountered in the watershed: irrigated “Protected Geographical Indication” (PGI) vineyard in an alluvial plain area, a “Protected Designation of Origin” (PDO) vineyard on shale and superficial soils in a mountainous area, a mixed PGI/PDO vineyard on clay-limestone slopes in a hilly area.

We organized five sets of collective workshops, with in-between modeling phases. This approach mobilized local stakeholders (PDO syndicates, cooperative wineries, agro-environmental public institutions and wine growers) and regional stakeholders (chamber of agriculture, technical institute, departmental council) to 1) share their perceptions of the impacts of climate change and the possible actions, 2) represent the local diversity of cropping systems (participatory mapping exercise), 3) discuss the results of simulations under future climate conditions without any adaptation, 4) build adaptation strategies, and 5) discuss their quantitative assessment and prioritize the adaptations.

We developed a simulation model composed of four modules : a grape phenological model (Morales-Castilla et al., 2020), a soil water balance model (Celette et al., 2010), a water-limited grape yield model (Naulleau et al., 2022), and an hydrological model (Lagacherie et al., 2010). The integrated model simulates the daily spatio-temporal dynamics of (i) water (infiltration, evapotranspiration, runoff), and (ii) grape production at plot and watershed scales. The impacts of climate change and adaptation strategies on these dynamics were assessed for the most pessimistic climate scenario (RCP 8.5), using data from the CNRM-ALADIN model.

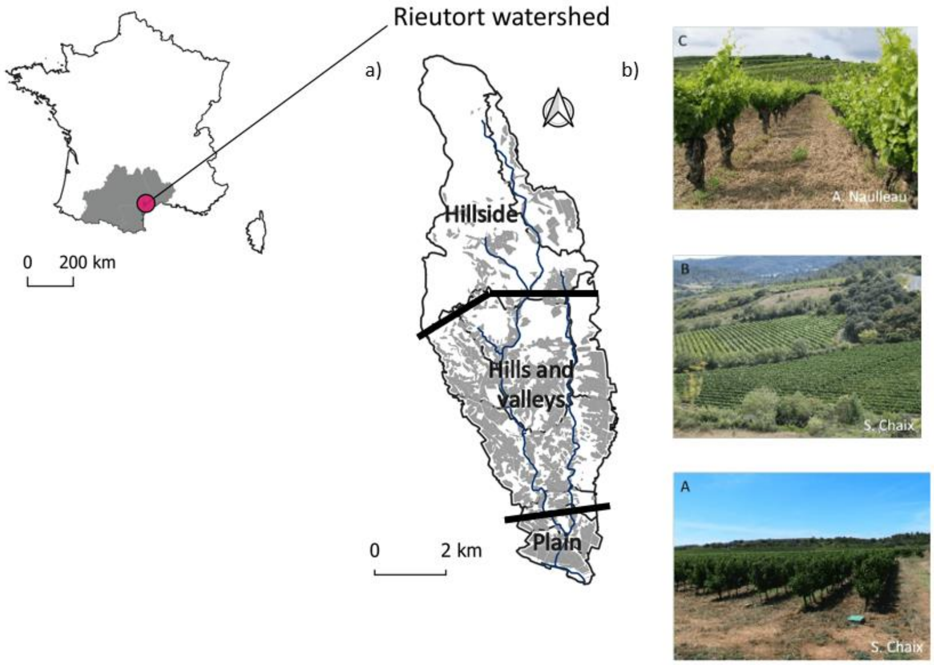

Figure 1. Presentation of the case study a) The Rieutort watershed with the vineyards in grey (source: RPG 2017), and the river streams in blue (source: BD CARTHAGE); b) three types of vineyard systems, from south to north: A) irrigated vineyards in the plain, B) vineyards in clay limestone terraces, C) “goblet” vineyard in the shale terroir

Results and discussion

The first results were based on the simulation of the reference situation described by stakeholders in the historical period (1981-2010), and for two time horizons (2031-2060, 2071-2100) under the RCP 8.5 climate scenario. The model predicted the advancement of phenological cycles (-11 and -20 days on the harvest dates for the 2050 and 2100 horizons), resulting in an increase in temperatures during berry ripening of 3 and 6°C for these two time horizons, respectively. The total grape production would decrease by 10 and 14% (for the 2050 and 2100 horizons, respectively) although the irrigation water supply would double in the irrigated sectors (Figure 2). The mobilization of stakeholders in the modelling process has made it possible to take into account the spatial heterogeneity of the environment (soils, climate), and of cropping systems (grape varieties, densities, cropping practices) (Naulleau et al., 2022). PDO production systems, located in the north of the watershed and already constrained by water resources, would be less impacted in terms of yield losses (-0 to 10%) than PGI production systems located in the south of the watershed (-10 to -20%).

Based on the results of the climate change impacts, three adaptation strategies were designed by the stakeholders (Naulleau et al., submitted):

(1) delaying the harvest by using later grape varieties and promoting a cooler microclimate in the summer (hedges, row orientation, stock height),
(2) limiting water constraint by combining an extension of irrigated areas (from 10 to 30% of the surfaces) with water-saving practices (management of the leaf/fruit ratio, shading, mulching, reduction of planting density, adoption of drought-tolerant grape varieties),
(3) relocating plantations in space on a local scale.

Within the framework allowed by the numerical model, three adaptation strategies were simulated. Delaying the harvest date by planting late grape varieties showed a slight impact on harvest dates (- 1 week), with no important impact on average temperature during berry ripening (- 0.4°C). The strategy based on limiting water constraint through water-saving practices could compensate for the loss of production by 2050 at watershed scale, only if long-term adaptations would be taken (e.g. reduced planting density and shading) and irrigation would expand whenever possible (thus multiplying irrigation water inputs by 3 to 4 at the watershed scale at the 2050 and 2100 time horizons) (Figure 2). Finally, an extension of the vineyard of about 300 ha would compensate for the loss of production at the watershed scale, under the assumption that such extension would be technically possible and economically sustainable.

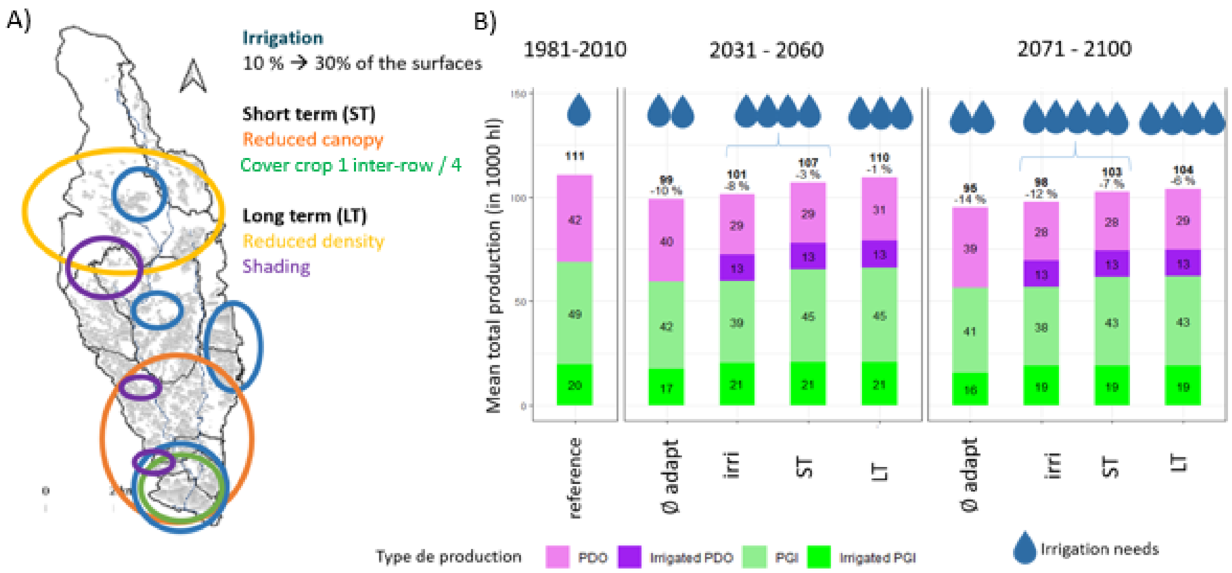

Figure 2. Impacts of the water constraint limitation strategies on the mean grape production and on irrigation needs at watershed scale. A) Spatialization of the adaptation levers according to stakeholders. B) Evolution of the production volume and irrigation needs under RCP 8.5, according to the different levels of the strategy: no adaptation, irrigation development (irri), short-term adaptation (ST), long term adaptation (LT). The number of blue drops at the top of the figure is proportional to the irrigation water requirement at the catchment scale (1 drop = 36 000 m^3). PDO: Protected Designation of Origin, PGI: Protected Geographical Indication.

Although the model helped at evaluating a certain number of adaptations and their combinations in space, it did not consider all the adaptations proposed by the stakeholders in the first steps of our participatory approach. Therefore, we ended our study with a qualitative analysis of the complete set of adaptation levers. Stakeholders were asked to classify these adaptation levers according to their feasibility and desirability. Our findings showed antagonisms between effectiveness, feasibility and desirability of some adaptation levers like irrigation and shading nets. Stakeholders highlighted three non-simulated adaptation levers as very feasible and very desirable: soil improvement, adaptive management of cover crop, and water-efficient training systems. They suggested to assess a fourth adaptation strategy of developing the exploration of the soil water reservoir by improving soil quality and favouring a deep rooting. This emphasized the importance of generating more knowledge, both quantitative and qualitative, in order to explore the full range of climate change adaptation options within the study area.

Conclusion

Our study proposed and implemented a participatory modelling approach for the co-design and evaluation of adaptation strategies of viticulture to climate change within a watershed. The joint work between stakeholders and modelers showed there is leeway for adaptation through a combination of technical levers, fitted to the local context (climate, soils, water resources, appellation areas, practices). The cumulative effects of several adaptation levers, targeted at specific locations in the landscape, can reduce yield losses due to climate change for the majority of winegrowing systems (irrigated/non-irrigated, PDO/PGI, deep/shallow soils). The participation allowed for a direct communication of the simulation results and their enrichment by qualitative indicators and experience sharing between workshop participants. Further studies could assess the specific effects of extreme events, the socio-economic drivers of changes particularly at farm level, and provide knowledge needed to assess promising adaptation levers such as soil quality improvement, water-efficient training systems, and reduced density.

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