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LONG-TERM ADAPTATION TO CLIMATE CHANGE IN VITICULTURE AND ENOLOGY : THE LACCAVE PROJECT

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Abstract

The LACCAVE project aims to study the impacts of climate change on the French wine industry and to analyze several adaptation strategies. It is a multidisciplinary project involving 23 different laboratories from INRA, CNRS and several French universities. The first part of this report describes the scientific context and rationale for the LACCAVE project and the known and predicted impacts of climate change on grape growing and berry ripening. Some directions for adaptation are also given. Finally, the 7 focus areas of the LACCAVE project are briefly described to give an overview of this ambitious study.

Key words : climate change, grape growing, wine making, adaptation, impact studies

Résumé

Le projet LACCAVE a comme objectif d'étudier l'impact du changement climatique sur la filière viti-vinicole française et d'analyser plusieurs stratégies d'adaptation. C'est un projet pluridisciplinaire qui implique 23 laboratoires de l'INRA, du CNRS et de plusieurs universités françaises. Cet article présente le contexte scientifique général du projet, ainsi que les impacts connus et prédits du changement climatique sur la culture de la vigne et la maturation des raisins. Des grandes stratégies d'adaptation sont également évoquées. Dans la seconde partie de l'article, les sept axes de travail du projet LACCAVE sont décrits brièvement afin de donner une idée générale de cette étude ambitieuse.

Mots clés : changement climatique, viticulture, œnologie, adaptation, études d'impact

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INTRODUCTION

The French wine industry, more than any other crop industries, needs to adapt to climate change. Given the socio-economic impact of wine production, the specific influence of climate on viticulture and wine quality, and the key issues of localization and innovations in this industry, INRA decided it was worthwhile to launch a multidisciplinary research project to explore not only the impacts of climate change on vine and wine but also the current and future adaptation strategies. The LACCAVE project brings together the expertise of 23 research laboratories and focuses on French wine producing areas. In close relationship with extension services and producer associations, this project aims at developing a common knowledge base on climate change issues, as well as gathering data, defining adaptation strategies and providing decision rules to address the critical issue of climate change adaptation for the wine industry.

CONTEXT

Climate change is already in progress. By the end of the XXIst century, the various simulations predict atmospheric CO_2 concentrations between 540 and 950 ppm. According to the IPCC (Intergovernmental Panel on Climate Change) expertise, average temperatures are expected to increase by 1.8 to 4 °C over the next century. With higher uncertainties, precipitations will increase slightly, along with drier summer in temperate zones, especially in Mediterranean countries. In addition to these average evolutions, climate change may increase spatial and temporal variability along with more frequent extreme events.

Even if reducing greenhouse gas emissions will likely have a positive impact on climate, climate change will go on because of the inertia of the earth's biophysical system and also because country policies are still not ambitious enough. Consequently, adaptation is crucial and should be considered as complementary to mitigation. Adaptation to climate change can be defined as the whole set of actions and processes that aim at adjusting natural and human systems in response to climate change in order to reduce its negative effects or take advantage of the positive ones. Even if climate change will generate costs to society, it will also bring new opportunities.

For these reasons, INRA has decided to support the multidisciplinary research program ACCAF (Adaptation to Climate Change for Agrosystems and Forests, INRA, 2011). The objective is to evaluate the risks associated with extreme climatic events and to define strategies for anticipating and preventing the consequences of such events., ACCAF also aims at (i) simulating the regional-scale impacts of climate change on agriculture and various ecosystems, (ii) understanding and controlling the major effects of climate change on biodiversity and ecosystem health, (iii) at adapting cultivated species and agricultural production systems to climate change, (iv) developing climate-friendly technological innovations that reduce greenhouse gas emissions, (v) identifying the costs and benefits of adaptation practices with regard to other issues (e.g., economic competitiveness, biodiversity, water and soil resources, quality), and (vi) defining common human organization pattern to enhance adaptive capacities to climate change.

WHAT DO WE KNOW ABOUT GRAPEVINE ?

Wine grapes (*Vitis vinifera*) are constrained to a narrow climatic range and consequently are especially sensitive to climate change, with potential effects on yield, quality and economic viability (Jones *et al.*, 2005). With the expansion of grapevine cultivation came the establishment of specific grape growing regions, whose climatic conditions played a decisive role in the production of typical wines from specific varieties and cultural practices (Schultz and Stoll, 2010). Climate traits, along with other environmental characteristics, have been used over time for the practical and legal delimitation of these regions or "terroirs". The French Appellation system took viticultural zoning one step further by adding regulations for practices and varieties to the legal definition of wine regions. Viticulture has developed very specific and codified relationships with geographical spaces and technologies. This is the reason why wine growing appears to be a "model agricultural system" allowing the evaluation of both the impacts of climate change and the implementation of adaptation strategies (Seguin, 2010).

The possible effects of climatic changes on grapevine development and ripening processes have been recently reviewed by several authors (Garcia de Cortazar Atauri, 2006 ; Holland and Smit, 2010 ; Duchêne *et al.*, 2010 ; Mira de Orduna, 2010 ; Schultz and Stoll, 2010). However, the long-term effects are difficult to predict, partially because many aspects (e.g., different varietal sensitivity regarding interactions between environmental parameters and plant adaptation mechanisms) are still largely unknown.

Temperature plays a major role in regulating plant phenology and there is a general agreement that the

timing of all the phenological stages will be advanced in the future: budbreak should be 3 to 18 days earlier in the second half of the XXIst century and the ripening period should be 20 to 40 days earlier compared to the last 30 years (Duchêne *et al.*, 2010; Garcia de Cortazar Atauri, 2006; Webb *et al.*, 2007; Pieri, 2010). This shift towards earlier, warmer ripening periods will increase the impact of temperature on the ripening process. Based on changes in grapevine phenology, Garcia de Cortazar Atauri (2006) has shown that a temperature increase of 4-6 °C in southern France and 6-8 °C in northern France may be observed during the ripening period. Most climatic indices show that some areas in the north of France will become more suitable for viticulture (Malheiro *et al.*, 2010).

The impacts of climate change on biomass production and fruit development are more difficult to predict, because of the combined effects of several parameters and varietal differences. Despite the fact that photosynthetic activity will be enhanced by rising atmospheric CO_2 content, it is likely that carbon assimilation may be down-regulated by sink activity. Moreover, plant respiration will also be intensified (Schultz, 2000). In a free-air CO_2 enrichment (FACE) experiment with Sangiovese, leaf area and total vegetative dry weight were increased to a greater extent than fruit dry weight (Bindi *et al.*, 1996a; Bindi *et al.*, 1996b; Webb *et al.*, 2007) and yield response to CO_2 enrichment was negative when temperature and solar radiation were also increased. Moreover, the reproductive response of grapevines to temperature was shown to vary among cultivars (Dunn, 2005). A more vigorous vegetative development may also increase water consumption and affect canopy structure, which in turn will have negative effects on vegetative and reproductive growth. Plant water status is expected to decrease after 2050, with negative impacts mainly in the south of France (Pieri, 2010). The control of grapevine water balance under modified climatic conditions (high CO_2, high temperature, low water content) will also be a key issue and water use efficiency has been reported to increase under these conditions (Schultz and Stoll, 2010). Root development will probably be affected as well, as shown for *Picea abies* (Lebègue *et al.*, 2004).

Grape ripening will be strongly affected both directly by modified environmental parameters and indirectly by the effects of these parameters on whole plant physiology, source/sink relationships and canopy microclimate. Ripening would occur under much warmer conditions than today, with major impacts on berry content and suitability to elaborate the current types of wines (Duchêne *et al.*, 2010). An increase in berry sugar content has already been reported for the last decades of the XXth century (Duchêne *et al.*, 2005). This is likely due to the progressive increase of solar radiation before and during the ripening period. A significant temperature effect on berry acidity has also been reported. Combined with an increase in potassium uptake, grape juice pH is strongly impacted (Kliewer, 1971; Coombe, 1987). Large varietal differences have been observed in the response of titratable acidity and pH to heating (Sadras *et al.*, 2013). Polyphenolic and aroma compounds, which are crucial for quality, will be affected quantitatively and qualitatively as well (Mori *et al.*, 2007; Sadras and Moran, 2012). The interactions between various environmental parameters such as extreme temperatures and light intensities are critical for this kind of compounds (Tarara *et al.*, 2008). Ultimately, changes in radiation quality will also strongly impact grape composition (Lafontaine *et al.*, 2005).

Climatic changes will also influence the incidence of various pests and diseases, affecting both the epidemiology and the susceptibility of cultivars to these pathogens (Mira de Orduna, 2010; Salinari *et al.*, 2007; Pangga *et al.*, 2011).

Most experts have highlighted the complexity of the issue of climate change at physical, biological, technical, social, economic and cultural levels, especially for viticulture and wine production (Jones and Webb, 2010). So far, there has been a lot of research on the impacts of climate change on the physical and biological aspects of viticulture. However, the extent to which climate change represents a risk or opportunity depends also on the capacity of grape growers and wine makers to adapt to changing conditions and only few studies have investigated this capacity (Holland *et al.*, 2010). An assessment of wine growers' perception of climate change in three European countries showed that most growers have perceived the changes in climatic conditions that occurred so far (Battaglini *et al.*, 2009). Impacts on yield, quality, and incidence of pests and diseases were noted with slight variations among countries. Options for adaptations varied among countries and the readiness to adopt adaptation measures was correlated with the degree of changes already planned, independent of climate change. Vulnerability approaches using system-based assessment showed that many factors have to be taken into account to evaluate the risks perceived by producers and the adaptation options they selected (Holland and Smit, 2010).

Large variations in climatic conditions do exist within viticultural areas, as a result of geomorphology, land

cover, and proximity of main water bodies and urban areas (Bois *et al.*, 2008). Environmental parameters (temperature, water, CO_2, soil mineral composition) will likely interact. Their combined effects on the numerous variety/rootstock combinations are difficult to predict, especially for fruit composition. Adaptation of technical practices and plant material will be crucial (van Leeuwen *et al.*, 2007 ; Ollat *et al.*, 2011). The relocation of vineyards to new areas would also represent an alternative. The adaptive capacity of the wine industry will be influenced by a number of economic, sociological and legal factors, and adaptive strategies will differ among wine regions (Hinnewinkel, 2007 ; Holland and Smit, 2010). Therefore, a global approach based on a combination of technological innovation, localization strategies and institutional changes is clearly needed to propose effective adaptation solutions.

THE LACCAVE PROJECT

LACCAVE is a 4-year project that aims at establishing a scientific framework to address climate change issues in viticulture. The project is coordinated by two scientists from Bordeaux and Montpellier and is organized in seven working groups. Over the course of the project, bridges will be built gradually between the working groups, and links with extension services and producer associations will be developed. LACCAVE is under the supervision of an international scientific board including scientists from Germany, Spain, USA, Brazil and South Africa. The different areas of focus are described below.

1. Characterization and perception of climate change

This working group aims at gathering and elaborating the basic information required for the project. By downscaling general climate prediction, it should provide regional climate simulations at different scale levels (small region, property) and for various periods of time (before 2050, from 2050 to 2100). It also aims at better evaluating how the various actors of the wine industry perceive climate change and at defining which parameters affect these perceptions. This information is crucial to develop adaptation strategies. In addition, this group will review existing knowledge on climate change for the project participants, considering their heterogeneity in terms of expertise and the need to share a common vision and a common vocabulary about climate change. Literature reviews will be released. Emphasis will be placed on plant health issues.

2. Physiological and genetic bases of grapevine adaptation to climate change

This working group aims at analyzing grapevine responses to major climatic parameters that may be affected by climate change (atmospheric CO_2 content, temperature, water) and at identifying the genetic mechanisms involved in such responses and the differences between scion and rootstock varieties. Traits related to phenology, vegetative growth, water consumption, berry development and fruit composition (sugars, acids, phenolic compounds and aromas) will be studied. The effects of modified berry composition and vineyard microflora on wine production processes will be analyzed as well. Results from the other research projects will be integrated in this working group using a systemic biology approach. This group will also work to coordinate experimental facilities to define common protocols for plant material description (phenotyping). The main challenge of this group is to elaborate modeling approaches that could be useful for vine performance simulations in future climatic conditions.

3. Development of technical innovations for adaptation to climate change

This working group aims at setting and studying technical practices to adapt vine growing and wine making processes to climate change. Enological practices will be considered to provide rapid direct answers to changes in berry composition. Several viticultural practices will be analyzed (plant density, soil management, training systems, pruning, fruit/leaf ratio), with a special focus on irrigation. The contribution of genetic diversity among existing scion and rootstock varieties will also be studied. One of the main objectives of this group will be to design cultural and varietal ideotypes based on grapevine requirements, achievements and adaptive potential.

4. Evaluation of the impact of technical innovations at a territorial scale

This working group aims at evaluating climate change impacts at a local scale (e.g., small wine growing region, water catchment area, terroir) taking into account current and new viticultural practices. It also aims at measuring the consequences of new adaptation practices (technical and migration) in terms of vineyard sustainability. Multicriteria evaluation methods including environmental parameters (water and soil resources) will be used for grape and wine typicity. The capacity and the limiting factors of producers to adopt adaptive practices will be studied by means of interviews and focus groups. Several case

studies will be performed in different vineyards (Val de Loire, Alsace, and Languedoc Roussillon). Researchers will specifically explore the assumption that local scale is a relevant level of adaptation, by combining different levels of action (including innovations) and taking advantages of the diversity and variability of local resources.

5. Analysis of the evolution of economic strategies

Climate change will impact production costs and the relationship between quality and geographical origins. These factors are crucial for the competitiveness of the wine industry at local, national but also international scale. This working group aims at studying the effects of climate change on producer marketing strategies but also on consumer taste and willingness to pay for new types of wines. If consumers accept the impact of climate change on wine quality, the need for radical changes in technical system will be less important. If consumers do not accept it, then maintaining a defined wine quality will become a big challenge for producers and researchers. Competition between wine producing regions and the contribution of regulation will also be analyzed. As a complete analysis is not possible, the group will focus on the evaluation of consumer perception and producer strategies to cope with the demand and the new production conditions, considering the cost of adaptation. The consequences of climate change on the competitiveness of the French industry at the European level will be evaluated. Finally, regulation systems, and especially the Appellation system, will be questioned.

6. Data management and analyzes

This working group aims at providing the partners with data management support. Existing data bases and information systems will be identified. An attempt to design specific information systems with shared sub-units will be made. Methodologies for analyzing and integrating complex data will be provided to participants.

7. Elaboration of strategic scenarios for 2050

This working groups aims at conducting a foresight study to build and explore strategic scenario for the adaptation of the wine industry to climate change. These scenarios will provide a conceptual framework to guide the LACCAVE project and will be updated using the results and expertise of the different working groups. The originality of the approach is to start from 4 pre-defined adaptive scenarios : a conservative scenario, consisting of only marginal changes, to assess the impacts of passive adaptation ; an innovative and technical scenario, focusing on changes in agricultural practices, to maintain existing vineyards ; a migration scenario taking into account the possibility for vineyards to move spatially according to climatic conditions ; and a zero-regulation scenario to test what happens when "anything is possible anywhere". The scenarios developed will be submitted to producers in different French wine regions in order to open a debate on this issue and define realistic strategies for each region. Without any doubt, a single strategy will not work. Adaptation will occur in many steps and via a unique pathway in each situation. The project does not aim at providing final solutions but tools that will help develop strategies, research and policy making.

CONCLUSIONS

The LACCAVE project was launched in March 2012 during a general meeting held at ISVV (Institut des Sciences de la Vigne et du Vin) in Bordeaux. In a first attempt to build a common knowledge among the partners, the meeting was introduced with several lectures on key aspects of climate change related to vine growing and wine producing. These lectures aimed at illustrating the different components of the project. The main information presented then is now reported in this special issue of the Journal International des Sciences de la Vigne du Vin.

An overview of perception and concern from representatives of grower associations in 5 major French wine regions will first be presented. The relationship between climate and wine typicity will be illustrated at an international level with a special focus on Ibero-American grape growing regions. Then the issue of downscaling climatic predictions at small wine region scale relevant to the adaptation process will be developed. The main results of the Climator project will also be reported for vine growing. By linking climatic prediction and crop models, Climator provided the first simulation of the impacts of climate change on several agrosystems in France. The issue of plant health will be of primary concern. In the second part of the document, adaptation will be considered and key issues linked to adaptation processes in terms of decision making will be analyzed. Finally, the potential use of some technical innovations to cope with climate change will be presented. Focus will be placed on plant material, training systems and enological processes.

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