# Adaptation strategies to climate change in the French wine industry: the role of networks connecting wine producers and researchers

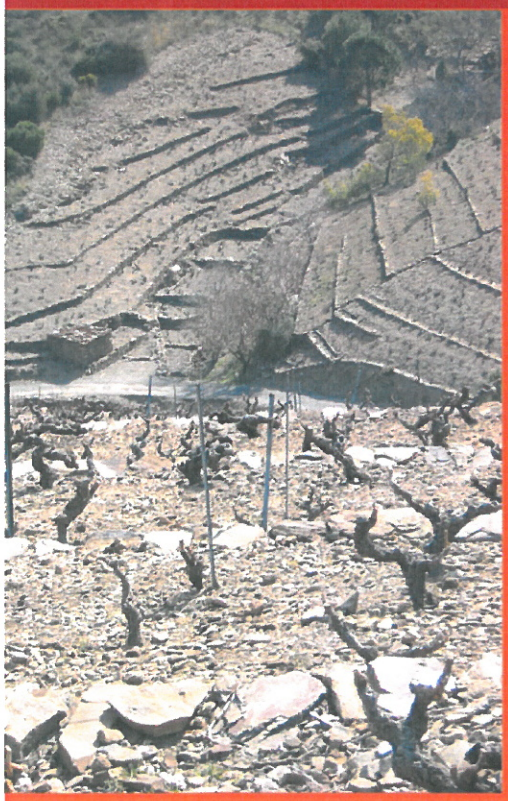
James Boyer, Jean-Marc Touzard

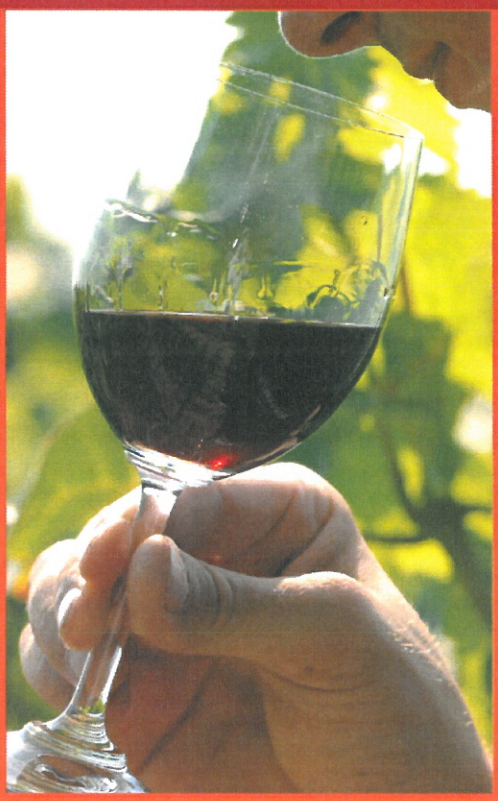
# Sustainable grape and wine production in the context of climate change

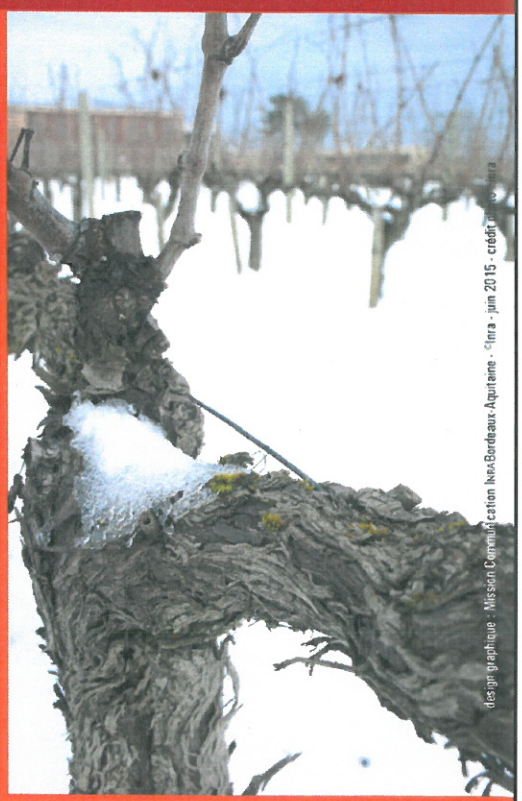
**April 10>13, 2016 - Bordeaux, FRANCE**

https://colloque.inra.fr/climwine2016

## CLIMWINE 2016 International Symposium







# Book of Abstracts

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BORDEAUX SCIENCES AGRO

# Sustainable grape and wine production in the context of climate change

Co-Convenors

N. OLLAT

I. GARCIA de CORTAZAR-ATAURI

J.M.TOUZARD

Bordeaux-France, April 10-13, 2016

Bordeaux Sciences Agro

1, cours du G$^{al}$ De Gaulle, Gradignan

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Bordeaux, 2016, the 15th of March

Dear colleagues,

The 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, it is worthwhile to explore not only the impacts of climate change on vine and wine but also the current and future adaptation strategies. Depending on the viticultural area under consideration, adaptation obviously raises distinct scientific issues. In all cases, however, it is clear that effective adaptation strategies will require a combination of different disciplines, technologies and approaches in both natural and social sciences.

Resonate this context, we are pleased to welcome you in Bordeaux under the auspices of the INRA ACCAF Meta-Program (Adaptation to Climate Change for Agrosystems and Forestry, projects LACCAVE and PERPHECLIM) to share 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. We hope you will get interesting scientific exchanges and unforgettable memories of this stay in Bordeaux. We did our best for that purpose.

Have a pleasant congress !

Nathalie OLLAT Iñaki GARCIA de CORTAZAR-ATAURI Jean-Marc TOUZARD

# The INRA metaprogramme on Adaptation of Agriculture and Forests to Climate Change (AAFCC)

T. Caquet[1], N. Bréda[2], J.-P. Amigues[3], C. Gascuel[4], K. Chalvet-Monfray[5], P. Debaeke[6], J.-M. Touzard[7], J.-F. Soussana[8]

[1]*INRA, UAR 1275 Ecology of Forests, Grasslands and Freshwater Systems Division, Champenoux, France*

[2]*INRA, UMR 1137 INRA-Université de Lorraine "Forest Ecology and Ecophysiology-EEF", Champenoux, France*

[3]*INRA, UMR 1081 INRA-CNRS-Université Toulouse I "Laboratoire d'Economie des Ressources Naturelles-LERNA", Toulouse, France*

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[6]*INRA, UMR 1248 INRA-INPT "Agroecologies Innovations Ruralities-AGIR", Castanet-Tolosan, France*

[7]*INRA, UMR 0951 INRA-CIRAD-Montpellier SupAgro, "Innovation", Montpellier, France*

[8]*INRA, Collège de Direction Paris, France*

The metaprogramme on Adaptation of Agriculture and Forests to Climate Change (AAFCC) has been launched by the French Institute for Agricultural Research in 2011. It aims at coordinating, promoting and integrating the research activities to overcome the scientific and societal barriers that could restrict adaptation. This proactive and pluridisciplinary strategy involves cooperation with French and foreign academic and socioprofessional actors. It should ensure rapid results and progress, for example in multi-criteria assessment of adaptation options. Favouring the dialogue between disciplines, AAFCC provides a framework for the various research projects on adaptation of agriculture and forests to climate change. Discipline-related skills in human and social sciences, agronomy, ecology, genetics, ecophysiology, animal sciences, economy and modelling are mobilised to cover the range of questions raised by adaptation to climate change. The chosen strategy focuses on integrated approaches at the sector or territorial level. The issues and general objectives of the programme can globally be ordered according to the increasing response times of the systems, from short- to long-term, and the intensity and 'active' nature of the adaptation: from palliative or support actions, to innovation and technical or collective organisational breakthroughs. Such breakthroughs require strong innovations and a thorough socio-economic assessment.

AAFCC is fully in line with the European Joint Programming Initiative on "Agriculture, food security and climate change", initiated to enhance coordination of national research programmes. Research projects address annual and perennial crops, livestock, forests, biodiversity or water and soil resources. AAFCC has also promoted training of young scientists through PhD grants and postdoctoral fellowships. Since 2011, AAFCC has supported more than 25 national research projects and international actions and networks. It supports various European-level initiatives through funding of some ERA-NETs. It also supports international (for example cooperative projects with India or south Mediterranean countries) or global (for example ensemble crop modelling) projects. International actions increase the range of climate conditions and model species under investigation. Considering the issues at stake, international cooperation is undoubtedly, along with pluridisciplinarity, the most important issue in this domain. This is the reason why AAFCC supports various European-level initiatives and international or global projects in addition to national projects. The metaprogramme also supports, in the framework of an action led with Allenvi, the formalization of the specifications for and the implementation of a portfolio of adaptation services at a national scale, based on products coming from agro-hydro-climate modelling chains.

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***Acknowledgments :*** *we are grateful to the below mentioned organizations which supported the organization of the congress*

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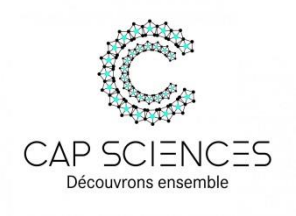


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# SYMPOSIUM PROGRAM

## Sunday, the 10th of April — CAP Sciences - Hangar 20 - Quai de Bacalan - 33300 Bordeaux

| | | | |
|---|---|---|---|
| 17h00 | **Beginning of registration** | | |
| 18h00 | **Opening ceremony** | | |
| 18h30 | | **J.F Soussana, France** | Climate change, a challenge for agriculture |
| 18h50 | | N. Ollat, J.M. Touzard, I. Garcia de Cortazar-Atauri | Laccave : a research program about the adaptation to climate change of the french wine industry |
| 19h00 | | Alain Rousset, Chairman of the Aquitaine-Limousin-Poitou Charentes regional council - Representants of Conseil Interprofessionel du Vin de Bordeaux and of the organising institutions (INRA, ISVV, Bordeaux Sciences Agro) | |
| 19h30 | **Cocktail** | | |

## Monday, the 11th of April — Bordeaux Sciences Agro - 1 cours du Général De Gaulle - 33170 Gradignan

| | | | | |
|---|---|---|---|---|
| 8h00 | **Registration and poster installation** | | | |
| 8h30 | | The convenors | Few words about the symposium | |
| 9h00 | **Introduction lecture** | **Pr G. Jones, *USA*** | The State of the Climate: Trends, Projections, and Relationships to Viticulture and Wine Production | Page 17 |

| **session 1** | **Chairwoman** | | **V. Bonnardot** | **Climatic modelling at different scales** | |
|---|---|---|---|---|---|
| 9h30 | **Keynote speaker** | | **Pr A. Sturman, *New Zealand*** | The application of high-resolution atmospheric modelling to weather and climate variability in vineyard regions | Page 19 |
| 10h00 | | 1 | I. Garcia de Cortazar-Atauri, *France* | Assessment of future climatic conditions in French vineyards. Consequences for defining adaptation strategies | Page 20 |
| 10h15 | | 2 | R. Le Roux, *France* | Nested scale approach to characterize climate aspect of vineyard terroirs in a context of climate change | Page 21 |
| 10h30 | | 3 | A. Soret, *Spain* | Climate predictions for vineyard management | Page 22 |
| 10h45 | | 4 | A. Nesbitt, *UK* | Impacts of recent climate change and weather variability on UK viticulture - combining weather and climate records with producers' perspectives | Page 23 |
| 11h00 | Poster presentation | | | | |
| 11h10 | Pause | | | | |

| **session 2-1** | **Chairman** | | **P. Lagacherie** | **Impacts of climate change** | |
|---|---|---|---|---|---|
| 11h30 | | 5 | H. Fraga, *Portugal* | Climate change impacts on viticultural yields in Europe using the STICS crop model | Page 33 |
| 11h45 | | 6 | M. Hofmann, *Germany* | Climate change, water budget and grapevines in Germany | Page 35 |

| | | | | |
|---|---|---|---|---|
| 12h00 | 7 | E. Edwards, *Australia* | Multi-seasonal effects of warming and elevated $CO_2$ on the physiology, growth and production of mature, field grown, Shiraz grapevines | Page 36 |
| 12h15 | 8 | S. Zito, *France* | Powdery mildew evolution in cool climate regions in response climate change: The example of Burgundy | Page 37 |
| 12h30 | 9 | F. de Herralde, *Spain* | Potential changes in water deficit and phenology of grapevine under climate change conditions in NE Spain: A modeling approach to watershed level | Page 38 |
| 12h45 | Poster presentation | | | |
| 13h00 | Lunch | | | |

| **session 2-2** | **Chairman** | **B. Bois** | **Impacts of climate change** | |
|---|---|---|---|---|
| 14h30 | 10 | Y. Wohlfahrt, *Germany* | Elevated $CO_2$ concentration: Impact on growth and grape quality of Vitis vinifera cv. Riesling and Cabernet Sauvignon for two accompanied vintages | Page 39 |
| 14h45 | 11 | S. Marchand, *France* | The 2003 vintage, an anticipation of future Bordeaux vintages in a context of climate change? | Page 40 |
| 15h00 | 12 | U. Leibar, *Spain* | Grapevine nutritional status under different soils and future expected climate conditions | Page 41 |
| 15h15 | 13 | J. Zhu, *France* | Simulating the effect of climate change on berry composition using whole plant model | Page 42 |
| 15h30 | 14 | MC. Ramos, *Spain* | Phenology variability, and predictions under climate change scenarios, of Cabernet Sauvignon and Tempranillo cultivated in the Ribera del Duero DO | Page 43 |
| 15h45 | Pause | | | |
| 16h05 | Poster presentation | | | |

| **session 4-1** | **Chairman** | **E. Giraud-Héraud** | **Perception and adaptability of climate change by the actors** | |
|---|---|---|---|---|
| 16h15 | 15 | P. Aigrain, *France* | Lessons from a foresight exercise on the French wine industry under climate change | Page 117 |
| 16h45 | 16 | G. Pickering, *Canada* | Climate Change adaptation requires integrated, transdisciplinary research across the value chain: a case study of the Ontario Grapevine and Wine Research Network | Page 118 |
| 17h00 | 17 | MC. Pichery, *France* | Climate Change and economic challenge strategies for vinegrowers, winemakers and wine estates | Page 119 |
| 17h15 | 18 | C. Foss, *UK* | Climate change and sustainability in English wine production | Page 120 |
| 17h30 | 19 | A. Strever, *South Africa* | Sustainable wine production in South Africa within the context of climate variability | Page 121 |
| 17h45 | 20 | E. Neethling, *France* | Assessing local climate vulnerability and winegrowers' adaptive processes in the context of climate change | Page 122 |
| 18h00 | 21 | J. Gautier, *France* | The french wine AOC and the challenge of climate change | Page 123 |

*18h30 Departure by bus to the Hotel de Region, Bordeaux downtown*

*19h00 Reception by the Aquitaine Council*

*20H30 Free evening*

## Tuesday, the 12th of April

| session 5 | Chairwoman | A. Parker | Ecophysiology for climate change | |
|---|---|---|---|---|
| 8h15 | Poster presentation | | | |
| 8h30 | **Keynote speaker** | **Pr H. Le Treut, *France*** | **Climate change : from global to local issues** | |
| 9h00 | 22 | L. Torregrosa, *France* | Grapevine and climate warming: Duravitis program opens new breeding strategies for temperature adaptation | Page 60 |
| 9h15 | 23 | A. Coupel-Ledru, *France* | A combination of phenotyping, genetic and physiological approaches to guide breeding for efficient water use in grapevine | Page 61 |
| 9h30 | 24 | T. Scholasch, *France* | Predicting the effects of drought and climate change on the composition and extractability of flavonoids in Cabernet Sauvignon | Page 62 |
| 9h45 | 25 | J. Considine, *Australia* | Summer and autumn, not winter, matter in dormancy of the grapevine | Page 63 |
| 10h00 | 26 | E. Marguerit, *France* | How do rootstocks control scion water use efficiency? | Page 64 |
| 10h15 | 27 | C. Delmas, *France* | Will grapevine pathogens adapt to climate warming? Temperature reaction norms of life-history traits in grapevine downy mildew | Page 65 |
| 10h30 | Poster presentation | | | |
| 10h40 | Pause | | | |

| session 3-1 | Chairman | A. Strever | Adaptation to climate change | |
|---|---|---|---|---|
| 11h00 | **Keynote speaker** | **Pr H.R. Schultz, *Germany*** | **Issues to be considered for strategic adaptation to climate evolution** | **Page 91** |
| 11h30 | 28 | Pr C. van Leeuwen, *France* | Modified grape composition under Climate Change conditions requires adaptations in the vineyard | Page 92 |
| 11h45 | 29 | E. Forrestel, *USA* | Projections of Suitable Wine Growing Regions and Varieties: Adaptation in Space or Place? | Page 93 |
| 12h00 | 30 | F. Vinatier, *France* | How to translate narrative scenarios in landscape dynamics: Application to the introduction of irrigation in vineyards | Page 94 |
| 12h15 | 31 | F. Alves, *Portugal* | Vineyard drought adaptation in the Douro demarcated region | Page 95 |
| 12h30 | 32 | E. Delay, *France* | Cooperative winery can be a major actor to adapt viticulture locally? | Page 96 |
| 12h45 | 33 | G.Teil, *France* | Climate change and adaptation: Alsace and Loire Valley vintners' challenging point of view | Page 97 |
| 13h00 | Lunch | | | |
| 14h00 | Departure for technical visit in St Emilion | | Field visits, Château visit and Wine Tasting<br>Variability in climate and topology within a producing area : a way to adapt ? | |
| 19h00 | Gala dinner in St Emilion | | | |

## Wednesday, the 13th of April

| session 3-2 | Chairwoman | | F. de Herralde | Adaptation to climate change | |
|---|---|---|---|---|---|
| 8h30 | | 34 | P. Vivin, *France* | Process-based models for analysing grapevine genotype adaptation to climate change: issues and challenges | Page 98 |
| 8h45 | | 35 | E. Duchêne, *France* | How can grapevine genetics contribute to the adaptation to climate change? | Page 99 |
| 9h00 | | 36 | J. Tardaguila, *Spain* | New plant phenotyping technologies in a changing climate | Page 100 |
| 9h15 | | 37 | J.M. Sablayrolles, *France* | How to adapt winemaking practices to modified grape composition under climate change conditions? | Page 101 |
| 9h30 | | 38 | L. Santesteban, *Spain* | Severe trimming and enhanced competition of laterals as a tool to delay ripening in Tempranillo vineyards under semiarid conditions | Page 102 |
| 9h45 | | 39 | T. Dufourcq, *France* | Should water supply by irrigation be soon a technique to manage aromatic potential of Colombard in South-Western France Gascony vineyard? | Page 103 |
| 10h00 | | 40 | A. Parker, *New Zealand* | Canopy manipulations to delay ripening: A case study for Pinot noir and Sauvignon blanc | Page 104 |
| 10h15 | poster presentation | | | | |
| 10h25 | Pause | | | | |

| session 4-2 | Chairman | | P. Darriet | Perception and adaptability of climate change by the actors | |
|---|---|---|---|---|---|
| 10h45 | **Keynote lecture** | | **Pr . J.M Gil, *Spain*** | Does alternative choice experiment formats matter to elicit preferences and willingness to pay? | Page 116 |
| 11h15 | | 41 | L. Charlier, *France* | Climate change: issues and actions for the Bordeaux wine industry | Page 124 |
| 11h30 | | 43 | A. Ugaglia, *France* | Adaptation Strategies of Bordeaux's winemakers to face climate change | Page 126 |
| 11h45 | | 44 | J. Boyer, *France* | Adaptation Strategies to Climate Change in the French wine industry : The role of networks connecting wine producers and researchers | Page 127 |
| 12h00 | | 45 | A. Fuentes, *France* | Is global warming desired by wine consumers? | Page 128 |
| 12h15 | | 46 | J. Rochard, *France* | Reducing the impact of greenhouse gases on wine sector : situtation in France and approach by the OIV | Page 129 |
| 12H45 | **Concluding talk** | | **T. Caquet, *France*** | The INRA metaprogramme on Adaptation of Agriculture and Forests to Climate Change (AAFCC) | Page 5 |
| 13h00 | Farewell communication | | The convenors | | |
| 13h30 | Lunch | | | | |

# POSTER PRESENTATION

| | Posters | **Sustainable grape and wine production in the context of climate change** | |
|---|---|---|---|
| | Name, Country | Title | Page |
| | **Session 1** | **Climatic modelling at different scales** | |
| 1 | M. Eveno, *France* | Atmospheric circulation patterns and local weather types: a combined study of climate variability in Saint Emilion vineyards | Page 25 |
| 2 | N. Fontes, *Portugal* | High-resolution agrometeorological observations to assess impact on grape yield and harvest date | Page 26 |
| 3 | M. Mota, *France* | Variability of grapevine phenology in Swiss vineyards bordering the Geneva Lake : influence of temperature and local atmospheric circulation | Page 27 |
| 4 | H. Quénol, *France* | Shifts in climate suitability for wine grape growing in the Cotnari (Romania) winegrowing region as effect of climate change | Page 28 |
| 5 | L. de Rességuier, *France* | Spatial temperature variability and distribution at local scale in Saint Emlion and Pomerol. | Page 29 |
| 6 | G. Sgubin, *France* | The future of the viticulture in Europe under discordant climate scenarios: the VINTAGE project | Page 31 |
| | **Session 2** | **Impacts of climate change** | |
| 7 | L. Allamy, *France* | Identification of « dried fruits » molecular markers found in Merlot and Cabernet-Sauvignon grapes and red wines | Page 45 |
| 8 | R. Biasi, *Italy* | Climate change in a Mediterranean grape-wine growing area: understanding variation in varietal phenology, berry maturation and health | Page 46 |
| 9 | B. Bois, *France* | Climate vs grapevine pests and diseases worldwide: The first results of a global survey | Page 47 |
| 10 | N. Cortesi, *Spain* | Grape sustainability in western South America: present climate assessment and climate change impact evaluation | Page 48 |
| 11 | E. Delay, *France* | CeLL, an agent based model for exploring spatial heterogenity influence of climat change on Lobesia botrana development | Page 49 |
| 12 | J. Drappier, *France* | HEAT BERRY: sensitivity of berries ripening to higher temperature - Grape and wine aromatic compounds | Page 50 |
| 13 | R. Kilmister, *Australia* | Multi-seasonal effects of warming and elevated CO2 on grape and wine composition of mature, field grown Shiraz grapevines | Page 51 |
| 14 | L. Leolini, *Italy* | Grape model implementation for studying the impact of climate change | Page 52 |
| 15 | P. Loussert, *Argentina* | Optical and SAR satellite images potential for vineyard monitoring in the climate change context | Page 53 |
| 16 | I. Pascual, *Spain* | Influence of elevated temperature on fruit yield and grape composition of thirteen Tempranillo grapevine accessions differing in cycle length | Page 54 |
| 17 | M.C. Ramos, *Spain* | Climate change effects on phenology and yield of three white varieties cultivated under rainfed conditions in the Penedès DO (NE Spain) | Page 55 |
| 18 | G. Sámson, *Hungary* | Expected growing season temperature increase in Eger wine district of Hungary based on regional climate modelling | Page 56 |
| 19 | J. Tonietto, *Brazil* | Estimating the Impact of Climate Change on Temperate, Subtropical and Tropical Grape Growing Regions in Brazil | Page 57 |
| 20 | J. Wu, *France* | “HeatBerry”: sensitivity of berry ripening to higher temperature - berry metabolism | Page 58 |

# *ABSTRACTS*

# The State of the Climate: Trends, Projections, and Relationships to Viticulture and Wine Production

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Climate change has the potential to greatly impact nearly every form of agriculture. However, history has shown that the narrow climatic zones for growing winegrapes are especially prone to variations in climate and long-term climate change. The observed warming over the last 50-100 years in wine regions worldwide has benefited some areas by creating more suitable conditions while others have been challenged by increased heat and water stress. Projections of future warming at the global, continent, and wine region scales will likely continue to have both beneficial and detrimental impacts through opening new areas to viticulture and increasing viability, or severely challenging the ability to adequately grow grapes and produce quality wine. Overall, the projected rate and magnitude of future climate change will likely bring about numerous potential impacts for the wine industry, including – added pressure on increasingly scarce water supplies, additional changes in grapevine phenological timing, further disruption or alterations of balanced composition and flavor in grapes and wine, regionally-specific changes in varieties grown, necessary shifts in regional wine styles, and spatial changes in viable grape growing regions. This presentation will 1) provide an updated look at climate trends in wine regions worldwide, 2) summarize the current state of the climate globally and the status of viticulture and wine production, and 3) review updated model projections in relation to viticultural viability and wine quality issues.

# *SESSION 1 : Climatic modelling at different scales*

## *ORAL*

# The application of high-resolution atmospheric modelling to weather and climate variability in vineyard regions

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Grapevines are highly sensitive to environmental conditions, with variability in weather and climate (particularly temperature) having a significant influence on wine quality, quantity and style (Jackson and Lombard, 1993; Jones et al., 2005; van Leeuwen et al., 2004). Improved knowledge of spatial and temporal variations in climate and their impact on grapevine response allows better decision-making to help maintain a sustainable wine industry in the context of medium to long term climate change. This new knowledge can be used in both operational decisions such as pruning regimes, canopy management, and response to frost and disease occurrence, and longer-term decisions such as selecting grape varieties to suit environmental conditions.

This paper reviews recent research in the application of weather and climate models that aims to improve our understanding of climate variability at high spatial (1 km and less) and temporal (hourly) resolution within vineyard regions of differing terrain complexity. The ability of the Weather Research and Forecasting (WRF) model to simulate the weather and climate in vineyard regions has been evaluated in South Africa, New Zealand and France. The main results of this research are summarised, with examples used to illustrate model performance in three very different environments. In South Africa, the WRF model has been applied at 500 m resolution in the complex terrain of the Stellenbosch wine of origin district (34°S), where thermal stress on the grapevine is often an important issue for the wine industry. WRF has also been applied at higher latitudes: i) in two cool climate vineyard regions of New Zealand (Marlborough and Waipara), where complex terrain has a major influence on temperature patterns and ii) in St. Emilion (France), where the terrain is comparatively simple and the climate less complicated.

WRF performs well in reproducing the temperature variability across these very different vineyard regions when compared to automatic weather stations. Coupling the atmospheric model with bioclimatic indices (e.g. Huglin, cool nights, Grapevine Flowering Véraison) has also provided useful insights into grapevine response to spatial variability of climate.

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# Assessment of future climatic conditions in French vineyards. Consequences for defining adaptation strategies.

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Grapes are one of the main crops in France. Even if it only covers 3% of the total cultivated area, it represents around 15% of the economic value of agriculture in France. Vineyards are located in very different regions through France, covering very different climates, contrasting soils, with widely varying production systems and using a large range of varieties. Current vineyards are the result of an adaptation work over centuries to reach a balance between soil, grape varieties, cultivation and winemaking techniques (van Leeuwen et al., 2004) to produce wines recognized worldwide. However current climate change may endanger this equilibrium and the economic balance of the system.

A suite of relevant ecoclimatic indicators were formulated and applied to investigate potential impacts of climate on French vineyards Ecoclimatic indicators are defined as agroclimatic indicators (e.g., high temperature days) calculated during specific phenological phases in order to take into account the plant response to climate (e.g., flowering- harvest) (Caubel et al., 2015). These indicators are linked with the ecophysiological processes which they characterize (for e.g., berry maturity).

These ecoclimatic indicators are calculated through the main vineyard regions in France (Alsace, Bordeaux, Burgundy, Champagne, Cognac, Rhone valley, Languedoc, Loire valley, Roussillon and South Western vineyards) using three different varieties representing different timing of development (Chardonnay-early, Syrah-middle and Cabernet Sauvignon-late). Phenological stages and indicators have been calculated using climatic data from 1950 to 2100 simulated by various global climate models (ARPEGE, IPSL) using current forcing scenarios (AR5 – RCP 2.6, 4.5 and 8.5). Phenology and indicators were calculated with PMP (Chuine et al., 2013) and GETARI software (Caubel et al., 2015) respectively.

Results described future climatic conditions for each vineyard, taking into account uncertainties dues to models, varieties and scenarios. These results can help stakeholders to define regional adaptation strategies to climate change.

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# Nested scale approach to characterize climate aspect of vineyard terroirs in a context of climate change

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Viticulture is an important practice across many regions worldwide, representing a key economic activity. Within wine growing regions, climate has a central role in the characterization of a specific vineyard terroir (Van Leeuwen et al. 2004; Jones et al 2006). As the grapevine is highly sensitive to climate variations, both spatially and temporally, climate change is one of the most important challenges facing the viticultural sector. Over the coming decades, wine growing regions will be confronted by a modification of regional climate characteristics that may lead to significant impacts on wine quality and typicality (Beltrando et Briche 2010; Neethling et al. 2012). Nevertheless, local climate and especially temperature variation could be very important adaptation responses to climate change.

In this study, a nested scale approach is applied to characterize climate aspect of vineyard terroirs. First, the climate structure of two French wine growing regions:Saint-Emilion and Anjou-Saumur is compared, using classic weather station coupled with dynamic climate model. We use climate data from DRIAS models, which are used for climate change projection. Bias between reality and modeling are calculated using weather station. Second, we study climate variability at fine scale using statistical modeling based on specific networks set up in study vineyard areas. Then we compare projection for the two site at regional scale and try to estimate impact of these at fine scale using locals models.

Results show that at regional scales, the effect of latitude is important between the two study areas. However, at fine scales the variability in climate conditions is more complex with some areas which present the same temperature characteristic in the two sites.

Working with a nested scale approach allowed the improvement of the knowledge about vineyard climate. In a context of climate change, this knowledge is essential to propose an adaptation of wine production for the futures decades without a loss of wine quality and specificity of each terroir.

# Climate predictions for vineyard management

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Predicting the future variability of atmospheric variables for the whole growth cycle of the wine can provide useful information to end users for crop management. For instance, if a warm year is expected, it is important to maintain the maximum of leaves as possible to protect the plant, while if a humid year is expected, it is important to reduce leaf coverage in order to avoid diseases and fungus. The earlier these decisions can be planned, the sooner unforeseen operational risks could be identified.

To estimate future climate variability over coming weeks or seasons, current practices use an approach based on retrospective climatology or persistence, with an assumption that the past will also represent the future. Recent advances in climate predictions can provide a more informative view by modeling future climatic variables over months or seasons. They analyze both the past climate system and its current state at the specific time when the prediction is created to provide the probabilities of different future outcomes, with an indication as to which will be the most likely. It has been demonstrated that climate predictions can improve upon using climatology at some spatial and temporal scales, so decision makers now have a new set of climate risk management tools that can strengthen their decision making.

In other sectors as hydropower or electricity generation and demand balance, climate information on seasonal-to-interannual time scales have already been illustrated for management decisions. Probabilistic climate forecasts come with a new set of challenges for end users: information is often untailored, hard to understand and apply in a decision-making context. EUPORIAS and IMPREX are projects funded by the European Commission to address these challenges and support the development of climate services in Europe. Furthermore, other ongoing parallel European projects (SPECS and PRIMAVERA) will deliver a new generation of climate forecast systems with improved forecast quality. Here we will present the state-of-the-art in climate predictions, some examples to illustrate their application to other sectors and their potential application for vineyard management.

# Impacts of recent climate change and weather variability on UK viticulture - combining weather and climate records with producers' perspectives.

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Cool climate viticulture in the United Kingdom (UK) has seen a recent (2004–2014) 148% increase in area to 1884 ha and a significant change in dominant vine varieties to Pinot Noir and Chardonnay for sparkling wine production. However, the specific influence of recent climate change in driving this trend, and the impact on yields of growing season temperature and precipitation trends, of inter-annual weather variability, and of extreme events has not been considered.

UK grape growers' perspectives on climate change and weather variability, sourced through an industry survey, were complemented by a quantitative analysis of climate and weather data (1954–2013) for the main UK viticultural regions: south-east and south-central UK. Regionally averaged monthly weather data was analysed and subjected to linear and stepwise regression analyses to determine its relationship with yield. Climate variability (2002–2013) was also mapped using higher spatial resolution downscaled output from the Weather and Research Forecasting (WRF) model. Spring frost events that negatively affected yield were highlighted by producers and evidenced using meteorological records.

Since 1993 all years have recorded a GSTave above the 1961–1990 mean of 13oC. Inter-annual (1989–2013) growing season precipitation and temperature variability is high but the magnitude of the variability has not changed significantly when compared with 1961–1990. Since 2004, and the change in dominant vine varieties, the relationship between UK wine yield and GSTave is statistically significant, however GSTave alone is shown not to reliably assure yield predictability. Higher temporal resolution temperature and precipitation data show a stronger statistical relationship with yield, particularly precipitation during flowering in June. No significant decreasing trend (1961–2013) in air frost day frequency was found in April or May, the critical months for bud-burst and initial shoot growth.

As identified by UK grape growers and through this work increasing GSTave superficially suggests enhanced UK cool climate viticultural opportunities, but critically masks the additional impact of shorter term temperature and precipitation events and high degrees of inter-annual variability that continue to threaten productivity. Furthermore, the recent change in dominant vine varieties appears to have increased viticultural sensitivity to climate variability. There is no evidence of a reducing risk of cool and wet conditions during flowering in June.
Most growers regard recent climate change as having contributed to the growth of the industry, but some see future climate change as a potential threat. This first quantitative and qualitative analysis of climate vulnerability in UK viticulture identifies threats and opportunities, and will help steer future climate change impact studies.

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# *SESSION 1 : Climatic modelling at different scales*

## *POSTER*

# Atmospheric circulation patterns and local weather types: a combined study of climate variability in Saint Emilion vineyards

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A combined study of atmospheric circulation patterns (Catalogue of European Large-Scale Weather Patterns adapted from the Hess-Brezowsky classification, published and updated by the Deutscher Wetterdienst) and of local weather types (method developed by O. Cantat, 2003) has been achieved to analyze the spatial and temporal climate variability at a fine scale. Precipitations (in mm), temperature (in °C) and insolation fraction (in %), recorded at the Bordeaux-Mérignac Météo-France station, have been related to average temperatures from each of the 90 sensors (TINYTAG data loggers) distributed over the vineyards of Saint-Emilion, near Bordeaux, as an experimental site of the European research program LIFE-ADVICLIM, coordinated by H. Quénol (LETG-Rennes). Several variables were selected using the records of minimum, maximum and average temperature recorded by the 90 sensors, including the daily temperature range or the amplitude of minimum and of maximum temperatures, in order to work at a fine scale. The analyzed period covers three years (2012, 2013 and 2014) and focuses basically on the growing season (from April to October).

The first results of the analysis highlight some findings. At first, throughout the whole territory and the studied period (i.e. the growing seasons of the years 2012, 2013 and 2014), the ten most recurrent (greater than 3% occurrence rate) local weather types (out of a total of 32 types) have been selected, thus facilitating the understanding of the results. The mild, clear and dry weather are the most frequent (respectively 21%, 10% and 24% of days), whatever the circulation pattern is. Conversely, the days with a mild, dry weather, and a grey sky are less frequent (whatever the circulation pattern). In addition, two main circulation patterns emerged: a North-West / North circulation and a South circulation (respectively 30% and 28% of days). Moreover, the most common combinations of atmospheric circulation pattern / local weather type are (1) a Northwest / Northeast circulation associated with a warm, clear and dry weather, and (2) a South circulation combined with a mild, grey and rainy weather.

This analysis will be improved using statistical tools and cartographic representations. The aim is to investigate further "extreme days" and their climatic features. The "wind speed" variable will be added to the definition of local weather type. The succession of weather types will also complete the study. Furthermore, regional analyzes (across different European vineyards) will be compared to the results obtained at local scale (in the vineyards of Saint-Emilion).

# High-resolution agrometeorological observations to assess impact on grape yield and harvest date

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Grapevine phenology, quality and yield are very dependent on weather at local scales. According to different studies, climate change is expected to advance grapevine phenological stages. Indeed, projections on grape maturity and harvest dates reported expected advances over years for many varieties across different winegrowing regions. The present work aims at providing high-resolution (vineyard-scale) data on grapevine phenology, yield and grape quality in four Portuguese wine regions: Alentejo, Dão, Douro and Vinho Verde. Climate data collection and analysis, between 2011 and 2015, through a network of weather stations (3 per vineyard, 1 vineyard per region) were performed, with each region displaying very different weather patterns and having contrasting geo-morphologies. High-resolution agrometeorological indices were calculated by means of organizing original data from each weather station into annual, growing season or important growth periods' stadia and subsequently used to derive bioclimatic indices (growing season temperature - GST, growing degree-days - GDD, cool night index - CI, and heliothermal index - HI) and extreme climate indices (ETCCDI). Comparison of region-reference with high-resolution bioclimatic indices showed significant differences and demonstrated the importance of vineyard-scale assessment for viticultural zoning. Observed extreme events were in agreement with projections for Portuguese wine regions. Moreover, a multivariate linear regression analysis of 5-year (2011-2015) time-series data of grapevine phenology, yield and grape quality against corresponding agrometeorological data has been performed. The resulting statistical model appears to be a valuable tool for production and harvest date prediction. Still, further validation is needed with longer time-series, so the model will continue to be updated as more data becomes available and periodically retested for accuracy. Compared assessments on the impact of climate change on grape growing and winemaking operations, across wine regions, should help actors of the wine industry to define strategies for higher long-term sustainability and profitability.

# Variability of grapevine phenology in Swiss vineyards bordering the Geneva Lake: influence of temperature and local atmospheric circulation

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The aim of this work was to contribute to increase knowledge on fine scale climate and its impact on grapevine phenology in Swiss vineyards bordering the Geneva Lake. Dates of budburst, flowering and véraison were monitored during three growing seasons (2011-2013) in 19 vineyards of Gamaret situated in proximity of the lake, yet in different other environnemental conditions. Harvest was performed each year at the same date and sugar content, total acidity and pH were measured in the grapevine must. Observed temperature data from sensors located in these vineyards as well as additional climatic data (windspeed and direction and relative humidity) from automatic weather stations of the federal AGROMET network were analyzed over the same period. Statistical analyses (PCA and cluster) were used to study spatial variability of phenology in relation to temperature. Results showed that there are significant correlations between Gamaret phenology and temperature (in terms of degree-days, high night temperature, duration with temperature below 12°C at night and daily thermal amplitude). Four groups of plots (sometimes relatively distant from each other) stood out of the cluster analysis with thermal amplitude as the main factor of differentiation in grapevine phenology. One of the clusters associated plots with early phenological stages, high sugar content and low acidity in the grapes. A significant spatial variability of temperature was shown in this small region generating different climatic conditions under which grapevine grow and berries ripen. At the same time, climatic analyses were performed at different scales to study the influence of the lake proximity and its contribution in the spatial temperature variability of the region. Despite the obvious influence of regional winds in this wine region, due to the geographical location between the Jura and the Alps mountain ranges, analysis of climatic data also showed the occurrence of local breezes on the shores of the Geneva Lake. The diurnal temperature variability observed in the vineyards was studied in relation to the local air circulation. Results showed that the breeze originating from the lake developed in the morning with impacts on temperature in the vineyards that varied as a function of its strength. Further investigation by means of atmospheric modeling could help in understanding the climatic impact in the vineyards in greater detail, while monitoring of grapevine phenology and berry composition is essential to provide data in order to study the viticultural and oenological impacts.

# Shifts in climate suitability for wine grape growing in the Cotnari (Romania) winegrowing region as effect of climate change

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Climate change modifies the multiannual averages of climatic parameters representative for the wine regions and along with it the grapevine growing conditions and typicity of wines that these regions produce. Wine regions around the globe are affected (Jones et al., 2005), but with different intensity of climate change and different consequences on grapevine from one wine region to another. Climate change is also felt in the temperate continental climate Dfb that characterizes Romanian viticulture. Recent studies from the NE part of the country, totaling about 20,000 ha vineyards, have revealed an increase, during the 1971 to 2000 time period, of the average temperature of January by 1.1 °C up to values specific to oceanic climate Cfb (Quenol et al., 2014). Vineyards in the region, which produced exclusively white wines, have started to produce red wine too in the last decade. This context has led to a study on climate change influence on the Cotnari vineyard, a representative one for the Romanian viticulture and for the viticulture of the temperate continental climate Dfb too. The paper presents the evolution of ten climatic parameters representative for the vineyard between 1961 to 2013 time period, and a comparative analysis of climate suitability for wine grape growing they generate for the 1961 to 1980 time period and 1981 to 2013 time period. Climate suitability for wine grape growing has been established by using a multi-criteria GIS based methodology and revealed as the fine-scale spatial distribution of types of wine production which vineyard's climate allows (Irimia et al., 2014). The results reveal the increase of helio-thermal resources of vineyard's topoclimate amid water resources constancy. As a result of these developments, the Cotnari vineyard topoclimate passed from its suitability for producing quality white wines (87.9% of the area) and white table wines (11.9% of the area) during 1961 to 1980 time period, to its suitability for red table wines (60.6% of the area) and quality white wines (39.2% of the area) during the 1981 to 2013 time period. The study reveals shifts of climate suitability for white wine production at higher altitudes, over 200 m a.s.l., and its replacement in the low zone of wine growing area (between 106 and 200 m a.s.l.) by climatic suitability for red table wines.

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# Spatial temperature variability and distribution at local scale in Saint-Emilion and Pomerol

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It has become possible to study spatial variability at fine scale, thanks to the recent evolution of new technology, especially the miniaturization of reasonably priced sensors.
Knowing the importance of temperature on vine development and wine quality, it is important to improve the assessment of climate variability for a better adaptation of plant material or training systems, particularly considering the recent evolution of the climate.

In this context, a substantial network of 90 temperature sensors has been installed in the famous winegrowing areas of Saint-Emilion and Pomerol which covers 12,500 ha of vineyards.
Each sensor has been positioned taking into account environmental parameters which can have an influence on temperature at local scale, including topography (altitude, exposure, slope), urban areas, rivers, latitude and longitude.

Initial results show great variability especially for minimum temperatures with an amplitude of up to 10°C on a given day, in particular during anticyclonic clear sky conditions without wind. In this case, relief plays an important role in spatial distribution, with warmest temperatures on the highest areas and cooler temperatures in the lower areas.

Spatial modeling of the Winkler index has been implemented over the area. This index is well adapted to study the influence of temperature on vine development. The result presents great amplitude of over 250°C.days in average during the years 2012 to 2014. The map of this index in 2012 (Figure 1) shows a spatial structure which is linked to the relief and environment parameters. The limestone plateau of Saint-Emilion and its south facing slopes are the warmest parts of the area. The North East of the area, the South East and the bottom of the valleys are cooler. Another warm part of the region, not specifically linked to the topography, is the western part of the area around the town of Libourne, including Pomerol.

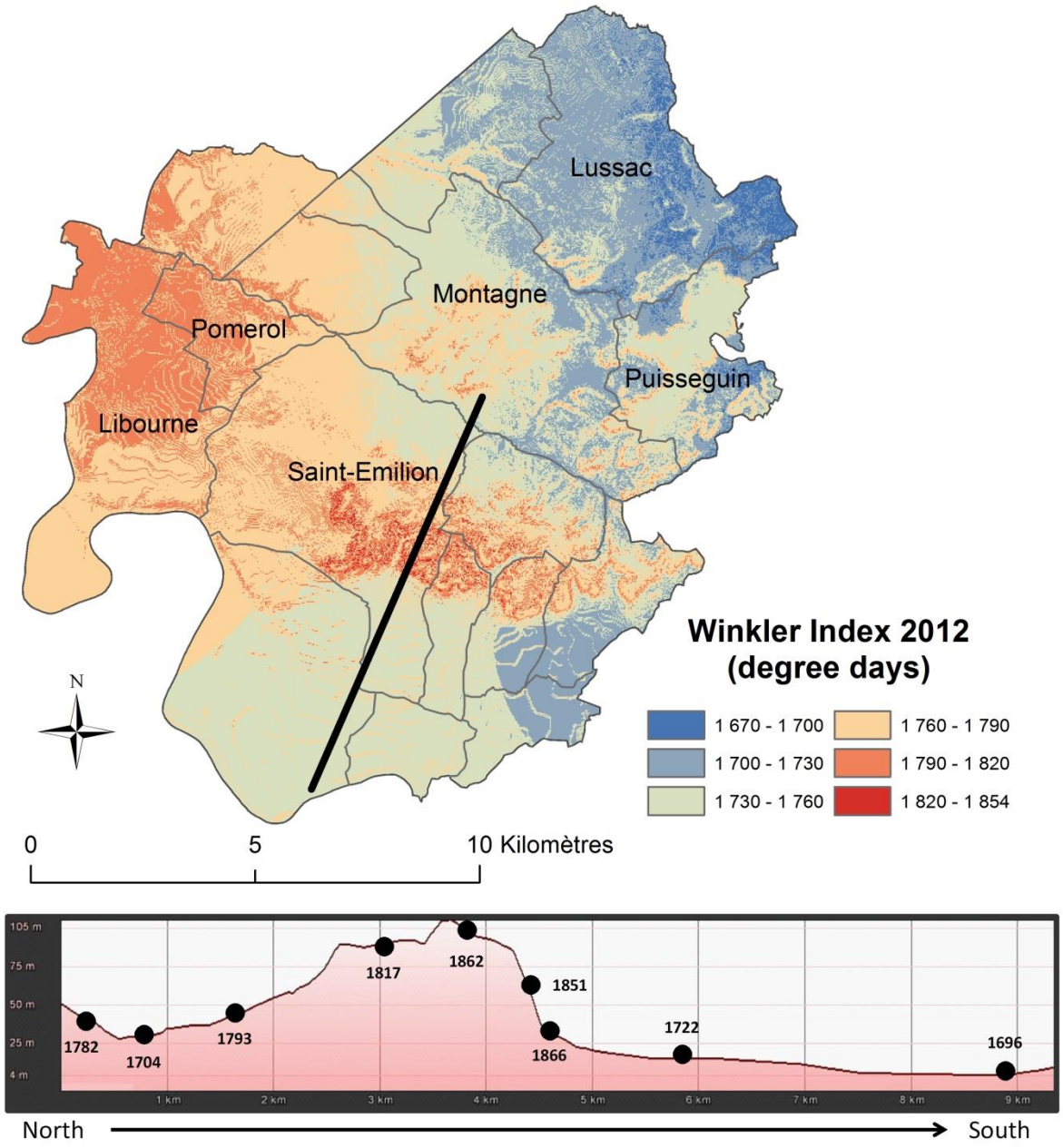


Figure 1: Spatial distribution of Winkler Index (2012) and a topographic sequence showing GDDs registered at specific sensors

# The future of the viticulture in Europe under discordant climate scenarios: the VINTAGE project

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Due to the critical influence of background climatic conditions on viticulture and wine quality, anticipating and understanding the future climate changes is a priority for winemakers all over the world. The last IPCC (IPCC, 2013) report strengthened the hypothesis that the increase in the atmospheric concentration of greenhouse gases since the industrial era have significantly contributed to the rise of global temperature observed in the 20$^{th}$ century (Levitus et al., 2001). Future projections, which are mainly based on the results of CMIP5 climate models (Taylor et al., 2012), reveal that the on-going global warming trend is expected to continue throughout the 21$^{th}$ century. Nevertheless, the CMIP5 models show a significant uncertainty over some region, which cannot be merely explained by the different model's climate sensitivity. The North Atlantic represents the most evident example. Indeed, in this region, different models show even opposite trends for the future temperature: while most of the models projects a warming trend, a subset of models shows an abrupt drop of temperature of several degrees in a few years. This rapid cooling, opposite to the general warming trend, is the effect of a local disruption of the pre-existing climate system associated to the oceanic convection in the subpolar regions (Sgubin et al., in revision). The occurrence of a convection collapse in a few models while not in the others gives rise to two main divergent scenarios over the North Atlantic, strongly influencing temperature and precipitation evolutions over the Europe, which would require distinct strategies of adaptation.

These evidences are at the base of the recently set-up VINTAGE project, aimed at analysing separately the different impacts of future climate change on viticulture over traditional regions of Europe. Here we present the main guidelines of the project, which mainly consists in three points: 1) mapping the different effects of climate changes on viticulture at global scale (coarse resolution) using different subsets of CMIP5 models; 2) Evaluating the viticulture zoning at regional scale (high resolution) through downscaling techniques from CMIP5 models; 3) assessing different adaptation measures for the viticulture in critical regions, e.g. the Bordeaux region, through a coupling of high-resolution climate models' results and a General Phenology Model. Preliminary results on the viticulture zoning at coarse resolution in Europe will be presented, stressing the different impacts driven by the divergent responses of oceanic convection in the North Atlantic.

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# *SESSION 2 : Impacts of climate change*

## *ORAL*

# Climate change impacts on viticultural yields in Europe using the STICS crop model

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Climate has a predominant role on growth and development of grapevines (Fraga et al., 2013). Consequently, climate change may become an important challenge to the winemaking sector. The present study aims to develop climate change projections for grapevine yields in Europe. For this purpose, gridded climatic variables over a recent-past (1950-2000) and RCP8.5 future scenario (2041-2060), are coupled with the STICS crop model (Brisson et al., 2008). For each grid-cell in the European sector, soil (e.g. type, texture, depth) and terrain parameters are used as model inputs. Grapevine and crop management parameters are also determined. Yield simulations under current and future climates are then compared to identify climate change impacts. For 1950-2000, the crop model is able to accurately simulate yields for the main current European wine regions, showing lower yields in Southern Europe and higher yields in more central/northern regions. For 2041-2060, the results depict an increase in yield in the later regions, and a decrease in the former, mostly over inner Iberia. The projections also show a northwards extension of the potential grapevine growth areas, emerging new potential winemaking regions up to 55ºN. The current study is a first attempt to apply the STICS crop model to the whole European sector, by using climatic, soil and terrain data as inputs. By using climate change projections as inputs to crop models, the present approach may represent a vital decision support system for the European winemaking sector.

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# Vintage Advancement and Compression in Australia due to Climate Change

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The shift in phenological development is the most conspicuous biological effect of recent warming, with advanced maturity of grapevines being reported for Europe, North America and Australia (Duchêne and Schneider, 2005 ; Wolfe et al., 2005 ; Petrie and Sadras, 2008). Between 1993 and 2006, maturity of grapevines in Australia advanced 0.5 to 3.0 d $y^{-1}$ or 9.3 ± 2.67 d $ºC^{-1}$ across a range of regions (Petrie and Sadras, 2008). Warmer temperatures and an advancement in maturity potentially impact on fruit quality and wine style, often causing 'unbalanced fruit' where high sugar levels are reached before optimum colour (and potentially flavour) development has been achieved (Sadras and Moran, 2012).

Associated with the advancement in maturity there have also been anecdotal reports of compression of the harvest period, with different varieties grown in the same region now reaching optimal maturity at similar dates and a narrower peak period over which a single variety matures. Given the capital intensive nature of the wine industry (processing capacity is used at most for 8-12 week per year) climatic trends that compress harvests have the potential to impact on financial viability.

This anecdotal evidence has been difficult to validate and quantify. Analysis of commercial maturity data, dating from 1995 to 2014, from a major Australian wine company suggested that vintage compression was being driven by two facets. Firstly, there was a consistent reduction in the time interval between maturities of different cultivars grown in the same region. For example in the McLaren Vale region the range in dates between peak maturity of the Chardonnay and the later maturing Cabernet Sauvignon was approximately 20 days in the mid 1990s and is now averaging closer to five days. The Shiraz matures between the Chardonnay and Cabernet Sauvignon and this is placing considerable pressure on winery infrastructure. Secondly, individual cultivars are also reaching maturity over a shorter period within one region. For example; Shiraz across the Barossa region (both Barossa and Eden Valley) reached maturity over a 30 day period in the mid 1990s and this has reduced to a 15 day window by the middle 2010s.
While this analysis does not allow separation of the effect of warming and management there have not been step changes in management practices during the study period. Regardless of the causes, the advancement in maturity and reduction in the duration of the window of peak maturity illustrate the challenges faced be wineries to process fruit over a shorter and more intense period.

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# Climate change, water budget and grapevines in Germany

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Extended periods without precipitation observed for example in Central Europe including Germany during the 2015 season, can lead to water deficit and reduced yield and quality for grapevines. Regional climate models project changes of precipitation amounts and patterns, indicating an increase of comparable situations in the future. In order to assess possible impacts of climate change on the water budget of grapevines, a water budget model was developed, which accounts for the large heterogeneity of vineyards with respect to their soil water storage capacity and potential evaporation as a function of slope and aspect and viticultural management practices. The model was fed with data from soil maps, a digital elevation model, the EU vineyard-register and regional climate models, allowing to conduct a risk assessment for the wine-producing regions Rheingau and Hessische Bergstraße on the scale of individual plots of land. The simulations showed that the risk for drought stress varied substantially between vineyard sites but might increase for steep-slope regions in the future.

# Multi-seasonal effects of warming and elevated $CO_2$ on the physiology, growth and production of mature, field grown, Shiraz grapevines

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Adaptation to climate change is of particular importance to perennial horticulture due to the longevity of plantings and, in the case of the wine industry, the role of fruit quality; crop value can vary by more than ten-fold depending on composition. To date, industry concern about climate change has largely focused on temperature, possibly due to the availability of vintage records, which have provided objective support for empirical observations of changes in grapevine phenology during recent decades. However, the effects of elevated atmospheric carbon dioxide concentration ($eCO_2$) - the primary driver behind climate change - on the physiology of leaves of $C_3$ plants have long been known, and, if applicable to grapevines, are likely to lead to wide-ranging effects on shoot growth, production and grape composition.

We previously developed open top chambers (OTCs) that used an active heating system to generate 2°C of warming in a mature vineyard, managed to current industry best practice. Those OTCs were subsequently augmented with a system to elevate $CO_2$ around the grapevines, thereby providing the capacity to impose warming and $eCO_2$ simultaneously; effectively simulating a future climate. Sixteen OTCs were established, in a Shiraz vineyard, together with additional non-chamber controls. Warming and $eCO_2$ were imposed in a complete factorial design with four replicates. Thus, the effect of $eCO_2$ could be separated from the effect of warming. The experimental system was fully operational prior to budburst in the 2013/14 growing season and has run continuously from that time on.

Our previous OTC work demonstrated that all aspects of vine phenology were advanced under 2°C of warming, but that there was little effect on leaf physiology. In contrast, as a $C_3$ plant, it was expected that the major effects of $eCO_2$ would be driven by changes in leaf physiology. Typically, plants grown under $eCO_2$ have higher rates of photosynthesis initially, but acclimate to $eCO_2$ over time, demonstrated by lower rates of photosynthesis than plants grown under ambient $CO_2$ when measured in a common atmosphere. An increase in photosynthesis of vines in the $eCO_2$ treatments was indeed observed, but, even with a canopy that had developed under $eCO_2$, very little acclimation to $eCO_2$ occurred. As a consequence, a year-on-year increase in vine non-structural carbohydrate (NSC) reserves was likely and initial sampling of woody material at the end of the first season suggested that this was indeed the case. The effects of warming alone corroborated the previous work, whilst no significant interaction between warming and $eCO_2$ was found during the first season on phenology, physiology or fruit composition. However, NSC is linked with factors such as shoot vigour, fruit-set and productivity, so an increase in vine NSC could be expected to lead to an incrementally more important interaction between warming and $eCO_2$ over a number of seasons. During the second season of the treatments, such an interaction on phenology was seen; maturation dates separating for the $eCO_2$+ambient temperature and $eCO_2$+warming treatments. The effects of the treatments on fruit and wine composition are provided in a partner presentation.

In conclusion, the limited acclimation of grapevine leaf photosynthesis to $eCO_2$ observed is likely to result in an increasing interaction between $eCO_2$ and climate warming over a number of seasons, requiring changes in vineyard management to prevent negative impacts on fruit composition.

# Powdery mildew evolution in cool climate regions in response climate change: The example of Burgundy

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Vitiviniculture worldwide is currently facing two major challenges: adapting to climate change and reducing its environmental footprint. Plant protection is a central aspect of both of these challenges, because pest and diseases development is strongly controlled by climate conditions, and because viticulture requires large quantities of pesticides to control pest and diseases. The current study addresses the changes in powdery mildew pressure in Burgundy in response to climate change. To assess the past evolution of powdery mildew risk, a time series of risk rates was built on the basis of expert annual reports about this disease in Burgundy. In addition, we created a comprehensive database including data on the yearly number of phytosanitary treatments for powdery mildew control. This database is based on the informations collected from 509 vine growers and includes each of the 4 subregions of Burgundy. . The number of yearly treatments has not changed significantly since the 1950's, despite considerable improvements in spraying technology,support systems innovations and collective policies towards a global reduction in pesticide use. To assess possible changes in disease pressure in response to climate change, we simulated powdery mildew primary contaminations on grapevine using (1) the BRIN and GFV phenological models, (2) a mechanistic model for *Erysiphe necator* and (3) statistically downscaled climate data from the SCRATCH08 project (CMIP3 A1B scenario from 10 GCM). Due to shifts in phenology timing in response to warmer temperatures, the duration of the sensitivity period of grapevine to powdery mildew is expected to be shorter in the future. The number of weeks during which the primary contaminations occurs (model simulations) appeared to be a relevant indicator for powdery mildew risk. The projections of this indicator for the mid and the end of the 21$^{st}$ century show values similar to present. These projections depend strongly on the GCM model from which the climate data used as input in the phenological/phytopathological models were downscaled

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Keywords: powdery mildew, grapevine, climate change, Burgundy

# Potential changes in water deficit and phenology of grapevine under climate change conditions in NE Spain: A modeling approach to watershed level.

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To evaluate the vulnerability to climate change of grapevine culture under Mediterranean conditions in the Siurana watershed (South Catalonia, NE Spain), net water needs of grapevine were estimated for the XXI century using a combination of downscaled climate projections (ECHAM5 plus MM5) in two IPCC scenarios (B1 and A2, SRES AR4), watershed hydrological model (SWAT) and FAO-56 procedure to calculate crop potential evapotranspiration. Changes in the growing cycle were estimated analyzing changes in temperature during the critical phenological phases. In comparison with baseline conditions (1984-2008), climate change projections predicted a 12% (B1) to 28% (A2) reduction in precipitation, and a 2.2º C (B1) to 3.6º C (A2) increment of mean annual temperature at the end of the century (2076-2100). The changes of the environmental conditions would affect water availability for grapevine: net irrigation needs (NIN) would increase significantly along the century, supposing an increasing of 9.3% to short term (2006-2030) in scenario A2, respect NIN average for the baseline period, 19 $m^3$ $ha^{-1}$ $year^{-1}$. The increasing in NIN respect baseline period would be very important for the long term period (2076-2100) assuming the worst scenario, 144 $m^3$ $ha^{-1}$ $year^{-1}$. Although it might seem not very high quantities of water irrigation, it would be critical in Siurana watershed where water irrigation comes mainly from rainfall and runoff collection in small reservoirs. The decrease in the amount of soil water availability along the growing season and the increasing potential evapotranspiration ($ET_0$) would be the main factors affecting the significant increase of water irrigation needs in grapevine. In areas where irrigation water is not and would be not available in the future, this will impose water restrictions on growth and impact the ability of grapevines to undergo the normal ripening and consequently could impact production and wine quality.

Changes in temperature would be directly related with phenology. The onset of the growing cycle could be advanced even in 13 days, the number of days with thermal stress could increase significantly and growing cycle could be shortened because of the quick heat accumulation (long term period "2076-2100" for A2 scenario) resulting in a new balance between alcoholic maturity and phenolic ripeness, a potential disruption in the climate-variety balance.
Results are showing the high vulnerability of winegrowing, despite its expanding technology, to changes in climate, and even more to site, plot, orchard, or terroir conditions.

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# Elevated $CO_2$ concentration: Impact on growth and grape quality of *Vitis vinifera* cv. Riesling and Cabernet Sauvignon for two accompanied vintages

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Facing the challenges of climate change an increase in atmospheric carbon dioxide ($CO_2$) has been predicted in various reports by the Intergovernmental Panel on Climate Change (IPCC). The benefits of increasing $CO_2$ levels under greenhouse environment have been well investigated for various crops. However, for perannial plants such as grapevines research under free carbon dioxide enrichment is hardly trialed. To investigate the response of field grown grapevines under elevated $CO_2$ conditions a FACE (Free Air Carbon dioxide Enrichment) facility for *Vitis vinifera* using cultivars Riesling and Cabernet Sauvignon was established at Geisenheim University (50°N, 8°E, Germany). The two varieties were planted in circular formation as triplicates and were exposed perennial to either ambient (400 ppm) or elevated (+ 20 %) $CO_2$ conditions.

Results showed that growth and vigor increased within two consecutive years (2014 and 2015) for both varieties grown under elevated $CO_2$ conditions. Measurements of summer pruning weight of the shoots were carried out in 2015 at two stages before and after veraison indicating a higher biomass production under elevated $CO_2$ conditions compared to ambient. Leaf area measured in 2014 and 2015 at the developmental stages of pepper corn size of the berries (modified E-L 29) and at veraison (modified E-L 35) showed similar tendencies. This will be of particular importance since growth and vigor impact on vine´s microclimate hence interfering with fruit composition and fruit health.

During the two accompanied ripening periods single berry weight, bunch architecture and bunch compactness altered. Riesling grown under elevated $CO_2$ showed an increased single berry weight and higher bunch compactness compared to vines grown under ambient conditions for both vintages. In terms of single berry weight similar results were achieved for Cabernet Sauvignon in 2015. In terms of yield no significant differences occurred for both varieties during vintage 2014. 2015 yield was significantly higher for both cultivars grown under elevated carbon dioxide conditions. Monitoring the occurrence of *Botrytis cinerea* elevated $CO_2$ concentration did not alter incidence nor frequency of this pathogen in Riesling during both seasons.

The obtained results over two vintages under elevated $CO_2$ conditions indicate first responses of field grown grapevine in respect to some vegetative and generative parameters. Investigations towards other physiological responses as well as the impact on fruit composition will be part of an ongoing study.

# The 2003 vintage, an anticipation of future Bordeaux vintages in a context of climate change?

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Even in old wines, the aroma and taste depends of the composition of the wine when it was young and of extrinsic physico-chemical parameters (such as temperature, light and oxygen). Some compounds can react, or can be separated from their precursors, to liberate odorous compounds. At the bottle opening, wines reveal the cards that were distributed during their youth. A part of the composition of mature wines is related to "terroir" parameters modulated by the vintage, viticultural and enological management. The extreme heat and drought of the 2003 vintage leads climate specialists to consider it as atypical. The climate of the 2003 summer may have produced an effect on secondary metabolite levels. The generation of aroma precursors and the natural selection of wild microbiota have probably been affected by these particular temperatures and water status. From these two observations, the question is: what are the consequences of the particular weather conditions of the 2003 vintage on the composition of 2003 wines today? If the composition of the 2003 vintage wines is singular, it might be a glimpse of the evolution of the expression of Bordeaux wines impacted by climate change. To try to answer the question, we have quantified several odorous and biogenic compounds in red Bordeaux wines from the 2003 vintage and in comparable wines from other vintages of the 2000 decade. In particular some compounds associated to the expression of the "bouquet of wines" have been studied. Results show that 2003 wines present atypical profiles, the so expected equilibrium and harmony of the "bouquet" seems to be lost. Among the more impacted molecules are tabanone (Slaghenaufi et al., 2014) presenting "spicy" and "tobacco" odorous notes and dimethyl sulfide (DMS) presenting "truffle" notes. DMS is also one of the key compounds of the expression of Bordeaux red wines "bouquet"(Picard et al., 2015) and contributes to enhance the fruity expression of red wines (Lytra et al., 2016). Another noticeable result concerns biogenic and volatiles amines (such as histamine, ethylamine and methylamine), these molecules are produced by the wine microbiota and are responsible of sanitary depreciations of wines (Leitão et al., 2000). The exceptional high levels of volatiles amines in the 2003 wines constitute a disquieting result. The hypothesis of a modification of wine microbiota or of young wine composition due to the climatic conditions can be proposed. This survey shows the particular organoleptic and sanitary status of old wines from the 2003 vintage. It emphasis the impact of heat and severe drought on the ageing potential of red Bordeaux wines which constitutes a key point of their personality. If 2003 vintage can be considered as an anticipative vintage, the bottles of 2003 opened today can help us to make a projection of the profiles of Bordeaux wines from the future.

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# Grapevine nutritional status under different soils and future expected climate conditions

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Nutrition is a relevant issue for winegrape growers because it influences grapevine growth, berry composition, as well as must and wine quality. In this work, we studied the effect of simulated year 2100 expected climate conditions (CC; 700 ppm $CO_2$, 28/18ºC, day/night and 33/53% relative humidity, day/night) versus current conditions (Curr; 390 ppm $CO_2$, 24/14ºC and 45/65% relative humidity) on the nutritional status of grapevine (*Vitis vinifera* L. cv. Tempranillo) fruit-bearing cuttings, grown under two water availabilities (well-irrigated vs. water deficit) and three soil textures (41, 19 and 8% of soil clay content). Plants grown under CC had lower Ca and N concentration in leaf blades than those grown under Curr at veraison and lower Zn and N at full maturity. Such result was associated with an increased number of leaves, although there was not a dilution effect due to a greater leaf biomass production. Leaf blades from droughted plants had higher Na and Mn concentration at veraison and full maturity, respectively, compared with those well-irrigated, mainly due to a dilution effect in well-irrigated plants. Well-irrigated plants showed lower concentration of Mn and Fe, only under CC. Calcium and Mn showed higher concentrations in more clayey soils at full maturity. Potassium concentration was higher in leaf blades of well-watered-plants in comparison to those of water-stressed plants because of a higher K mobility in moist soils, these differences being only significant at full maturity. Results suggest a moderate influence of climate change, water availability and soil texture on leaf nutrient content of grapevines.

Abbreviations: T – temperature; RH - relative humidity; CC - simulated year 2100 expected climate conditions; Curr - current conditions; WA – water availability; WI - well-irrigated; WD - water deficit; ST - soil texture; CEC - cation exchange capacity.

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# Simulating the effects of climate change on berry composition using whole plant model

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Climate change will affect various aspects of the wine industry and consequently challenge the sustainability of grape production. Most studies investigating the effect of projected climatic scenarios on grapevine focus on phenology, e.g. dates of flowering, veraison and maturity. However, there are fewer efforts aimed at studying the response of berry composition to climate change, which is essential in understanding how wine quality will be affected. Process-based models hold the potential to fill this gap by integrating berry development and quality formation with environmental factors. A novel grapevine model has been developed using the plant modelling software GroIMP. The model integrates the most advanced algorithms on: 1) coupling of photosynthesis and transpiration; 2) coordination of stomatal aperture, abscisic acid (ABA), transpiration and root conductance (Tardieu–Davies model, Tardieu et al., 2015); 3) balance of sugar loading and unloading via phloem sugar concentration (Baldazzi et al., 2013); 4) fruit growth (Dai et al., 2008); 5) nitrogen economy model within plant architecture (Bertheloot et al., 2011); 6) their interactions and feedback mechanisms. Whole plant xylem water potential and phloem sugar concentration were dynamically simulated based on environmental conditions (e.g. CO2, light, temperature, humidity, soil water content etc.). The xylem water potential and phloem sugar concentration were subsequently utilized by the berry growth module to simulate berry growth and sugar concentration. The model was calibrated through detailed experimental data and validated through comparisons with the published literature through simulations under a variety of virtual scenarios, e.g. different light and water stress conditions. The model simulations showed that water stress and shading both reduce the carbon assimilation but have differential effects on berry sugar concentration. Water stress reduces the xylem water potential and berry water import leading to none or slow reduction in sugar concentration, while shading increases xylem water potential and berry water import thus accelerating sugar concentration reduction.

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# Phenology variability, and predictions under climate change scenarios, of Cabernet Sauvignon and Tempranillo cultivated in the Ribera del Duero DO

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One of the most direct effects of climate change on grapevines is the change in onset phenology and the length of the growth season, which has further influences on the final grape quality and productivity. The knowledge and modeling of those changes may be a key tool to plan viticultural management practices in the near future under climate change scenarios. The aim of this study is the analysis of the variability in the dates of phenology affected by climate conditions and their predictable changes under different climate change scenarios. The study is based on the information provided by the Consejo Regulador of Ribera del Duero DO, referenced to four vineyards, planted with Cabernet Sauvignon and Tempranillo, which are located in the central part of the Ribera del Duero DO (Spain). The elevation ranges between 802 and 840 m. The phenology dates referred to the stages C (budbreak), F (visible bunches), I (bloom), M (veraison) and N (ripening) (according to the Baggliolini classification) were analyzed for the period 2004-2015. These dates were related to climatic conditions recorded in the period in the meteorological stations of Aranda de Duero. Average maximum and minimum temperatures, for the periods March-April_15$^{th}$, April_15$^{th}$-May, June_1-20$^{th}$, June_20$^{th}$-Aug_10$^{th}$ and Aug_10$^{th}$-Sep_30$^{th}$, considered as average periods between phenological stages (C–F; F-I; I-M and M-N), were used as predictors. Changes in phenology dates were simulated for the periods 2030, 2050 and 2070 using the average changes predicted using 10 models integrated in the Coupled Model Intercomparison Project (CMIP5) and for two Representative Concentration Pathways (RCP) scenarios – RCP4·5 and RCP8·5. The results showed that increasing Tmin and Tmax for the period before budbreak and between budbreak and bloom have significant effects on advancing all phenological stages, with greater advances for the stages F, I and M. For the scenario RCP4.5, the predicted advance of these stages ranged between 2.4 and 2.7 days and between 2.4 and 3.5 days for 2030 for both varieties; between 4.8 and 5.2 days and between 5.0 and 6.8 days for 2050; and between 7.5 and 8.8 days and between 7.8 and 8.6 days for 2070, respectively for Cabernet Sauvignon and Tempranillo. For the scenario RCP8.5 the differences between varieties were smaller. The predicted advance of the stage F ranged between about 3.2 days for 2030 and more than 10 days for 2070; the advance of bloom ranged between 4.6 days for 2030 and more than 10 days for 2070, and for veraison ranged between 3.1 days for 2030 and more than 10 days for 2070. The simulation showed that that harvest could be advanced, on average, up to 4 days under the scenario RCP4.5 and up to 8 days for the scenario RCP8.5.

Keywords: bloom, budbreak, RCP4.5, RCP8.5, temperature, veraison.

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# *SESSION 2 : Impacts of climate change*

## *POSTER*

# Identification of « dried fruits » molecular markers found in Merlot and Cabernet-Sauvignon grapes and red wines

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In the 2000s, aromas of dried fruits, referring to prune, fig or cooked peach are found more and more often in Bordeaux red wines. The markers responsible for these aromas related to the grape maturity are unknown.

The gas chromatography coupled to olfactometry (GC-O) and mass spectrometry (GC-O-MS) and GC-GC-O-MS analysis of musts and wines, that had shades of dried fruits aromas, allowed to confirm the realness of odorant zones reminding of the aroma of the samples. The analysis by GC-MS of number of musts and wines marked or not by dried fruits flavors show that the furaneol (caramel), the (coconut, cooked peach), the (Z)-1,5-octadien-3-one (geranium) take part in this aroma. Furaneol and γ-nonalactone are well known compounds in wines. On the contrary, the influence of the (Z)-1,5-octadien-3-one is reported for the first time in musts from healthy grapes. A quantification method of this ketone using SPME-GC-CI-MS was also validated in terms of repeatability, linearity, and limit of detection. The perception thresholds in model solution and must were determined.

The influence of the harvest date of Merlot and Cabernet-Sauvignon grapes on the aromas and fine composition of musts and wines is also specified in experiences that have been made in the vineyard. Moreover, we studied the incidence of winemaking processing of grapes that have been late harvested, even with a withered appearance, on the flavor of wine. These field studies are used to correlate the appearance of dried fruits nuances and the presence of molecular markers identified in musts and wines from overripe grapes.

# Climate change in a Mediterranean grape-wine growing area: understanding variation in varietal phenology, berry maturation and health

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It is widely recognized that *Vitis vinifera L.* is a specie very sensitive to climate change, so that it has been elected as a valuable bio-indicator. Climate is a key terroir determinant that affects yearly productions, grape quality traits and, indirectly, resource management and vineyard agro-ecosystem sustainability. Agriculture in the Mediterranean basin, that is one historical grape-growing area, has been reported to be endangered owing to environmental risk factors as soil consumption, land degradation, climate change. Here, the resilience of cultivated surfaces, i.e. of vineyards, could represent a primary challenge for landscape and biodiversity safeguard, ecosystem services preservation, historical and cultural value maintenance, as well as wine industry economy assurance.

The study aim was to investigate the response to climate change occurred in a traditional grape-wine producing area in central Italy (Latium region) in the recent past of some major national and local grapevine varieties, through the elaboration of climate indices and evaluation of shifts in phenology and productive behaviour.

To the aim historical series (1985-2014) for the main agro-climatic indices, i.e. Huglin, Winkler, Fregoni, Cool night index, number of days above 30°C, number of days below -2,5°C, were produced using data provided from on-farm climate stations. The tested varieties were the cvs Merlot, Syrah, Cabernet sauvignon, Cabernet franc, Sangiovese, Chardonnay and Grechetto white.

The effect of climate trends (at on farm–scale) has been analysed in terms of cultivar phenology, vine yield and grape quality (berry chemical traits) for the vintages 1995-2014; to this porpoise winery and yield registers have been used as data source.

The results highlighted for the study area an increasing trend for total thermal availability and a decrease in daily temperature excursion. These changes proved to be correlated to the seasonal grapevine growing cycle. In particular the cvs Syrah, Cabernet sauvignon, Grechetto white and Chardonnay tend to postpone grape physiological and technological maturation, while the cv Cabernet franc showed a reverse trend. Furthermore, grape technological quality proved to be modify in the considered span of time, in particular in terms of total soluble solids in the berries at the harvest time. The climate variability affected also berry health owing to its influence on agrochemical need. In fact, the results showed that in the last ten years the berry sanitary state has been heavily threated by phyto-pathogens (*Plasmopora viticola* and *Uncinula necator*) attacts.

Taken together these results suggest specific climate change adaptation techniques to cope with climate risks. Under the most negative climate scenario, certainly more attention should be paid in the management of plant diseases, in order to preserve the economical and environmental sustainability of the production. Given that the impacts of climate change are not likely to be uniform across all grapevine varieties, this evidence should address grape-growers to proper present and future strategies aiming a sustainable viticulture.

# Climate vs grapevine pests and diseases worldwide: The first results of a global survey

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Climate change consequences are either studied by means of historical data sets of field observations, controlled conditions experiments (mostly greenhouse or phytotrons) or using modelling with historical or projected climate data as variable input. Yet, the extremely large extension of viticulture worldwide offers the possibility to evaluate the consequences of climate variability on many aspect of the grape/wine growing system. In order to identify the bulk risk exposure to pest and diseases of vitiviniculture to climate, we initiated a global survey to retrieve the most important diseases/pest in many grapegrowing regions worldwide. Data collected was compared to the WorldClim gridded climate database to document the range of climate conditions (average growing season temperature or rainfall, dryness index…) associated to each of the reported disease/pest. The potential climatic-induced changes in a few examples grapevine diseases/pests geography in 2050 is assessed using agroclimatic indicators projection in 2050 from 19 models, using the RCP 8.5 scenario

# Grape sustainability in western South America: present climate assessment and climate change impact evaluation

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Viticulture is sensitive to climate change. Projecting the climate on decadal time scales is a valuable information for defining adaptive and mitigation measures on current wine regions. The Maipo wine region, for example, will likely be subjected to a high temperature increase of about 2º C during next 50 years, as well as many areas in the tropical regions.

At present, many regions with a high expected climate change are also difficult to study because of few or missing meteorological observations, few or no regional climate models available, high bias in the reanalysis data or models, and/or strong local effects due to complex geographical features. The western South America region is likely to experience significant impacts in the coming decades and it was chosen as a case study of a highly problematic area for assessing grape sustainability, due to a combination of the above mentioned limitations.

The aim of this study is to develop a methodology to identify potential areas for future wine plantation and detect future changes of the grape sustainability in the current wine regions. Six wine indexes were selected to identify the potential sites for grape plantation in 2050: the mean monthly temperature, the temperature from October to April, the Winkler index, the Winter severity index, the total annual precipitation and the precipitation from October to April. Such a set of wine indexes was firstly evaluated for past climate (1986-2005) using temperature and precipitation data from the ERA-Interim reanalysis dataset, and subsequently for future climate (2031-2050), estimating the wine indexes by means of a multi-model, multi-member ensemble of all the available CMIP5 global climate model simulations to follow a probabilistic approach and to better estimate uncertainties. Simulations both for the emission scenario RCP2.6 and for the RCP8.5 scenario were considered, to take into account the two more extreme emission scenarios. The impact of climate change on each wine index was estimated as the difference between its mean value for future climate (2031-2050) and its mean value for past climate (1986-2005).

Results of this study suggest that there are many potential areas with strong temperature and precipitation trends where future climatic conditions will be favorable for wine production, mainly due to widespread warming conditions in the tropical and extratropical regions, favoring grape plantation in regions that actually are not apt for grape. However, the lack of high-resolution data and models doesn't allow to study in detail specific sites, since local conditions (elevation, orientation, vegetation, prevalent wind direction, nearby water bodies or human activities, etc.) can greatly affect these results. Data and models can be partially adjusted to take into account some of these local effects using empirical relationships, even in the absence of a meteorological network in the area. The know-how developed for this study could also be applied to other world regions where wine companies want to explore the viability of viticulture in the coming decades.

# CELL, an agent based model for exploring spatial heterogenity influence of climat change on *Lobesia botrana* development

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The European Grapevine moth (*Lobesia botrana*) is one of the most noxious vineyard-pests in the European and Mediterranean area. Its larvae feed on grapevine flowers and berries, and usually cause considerable damage, also by facilitating saphrophytic infections to berries.
The biology of L. botrana has been investigated since the 80s. A number of studies has tested its physiology and behaviour in experimental conditions (Hurtrel and Thiéry 1999), in field conditions (Stockel et al. 1994), and using mathematical modelling techniques.

Whereas the modelling approaches that have been proposed in the literature are hetereogeneus they generally focus on the phenology and population dynamics of *L. botrana*, rather than analysing the role of spatial variability on its infestations and mating behaviour.

For this reason we propose here an agent based model (CeLL model), where we take into consideration spatial effects on L.botrana infestation dynamics. Our aim is to gain further insight into the processes and interactions occurring at the vineyard, population and individual level.

The use of agent based modelling allows us to integrate population dynamics within a spatial frame (the vineyard) where individual insects act by following development, movement and mating "rules".

In its first version, CeLL (Confusion Landscape Lobesia) focused on the identification of processes involved in pest infestations, necessary for the accurate simulation of infestation dynamics, as observed by the Groupement de Développement Agricole (GDA) of the cru Banyuls et des Albères. Here we attempt to obtain a more accurate simulation of the present situation in the same region, and make projections for the future, by the following actions:

1. We refine CeLL simulations by using accurate temperature input data, obtained by spatialising the high temporal frequency data from the TERVICLIM network
2. We apply climate change scenario to CeLL, to assess potential effects of climate changes on infestation dynamics and integrated pest management strategies.

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# Sensitivity of berries ripening to higher temperature - Grape and wine aromatic compounds

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The grapevine is an important economical crop and very sensitive to climate changes and microclimate. The observations of the last decades at a vineyard scale all agree to show the impact of climate change on vine phenology, resulting in advanced harvest (Jones and Davis 2000). Several authors found out that temperature affected metabolites, whereas only a few reported this impact on aromatic compounds on grape and wine, although high temperature were suspected to affect it negatively during ripening (Mira de Orduña 2010). It is well-known that the maturation conditions of grape berries are closely related to both young wines quality and their conservation and ageing capacity (hot vintages have resulted in wines with a lost typicité and precocious ageing aromas). One of the goals to the HeatBerry project is to finely analyze physiological mechanisms linked to the secondary metabolism in grapes, wine biochemistry and their modulation by microclimate. A passive heating system in polycarbonate screens has been set up at the vineyard. Field experiments showed 1-3 °C increase in berry temperature and were conducted on two cultivars: Cabernet Sauvignon and Sauvignon Blanc (5 ranks of each compound of 5 ceps). The experiment was repeated on the 2015 vintage. The heating system took place on June, periodically from August to harvest berries juices were analyzed for ripening analysis. The results were in accordance with previous studies. Microvinifications were performed on ripened (and over-ripened for Cabernet Sauvignon) berries for the two cultivars. Firstly, the wines were tasted; showing significant differences between wine from heated berries and non-heated berries. Secondly, aromas precursors (Glut-3-SH, Cys-3-SH, Glut-3-SH-Al) and glutathione were analyzed in berries. Analysis of varietals aromas, such as volatile thiols (3SH (3-sulfanyl-hexanol) and 4-methyl-4-sulfanyl-pentan-2-one (4MSP)), were conducted on wines. Finally, the results are expected to be in agreement with the tasting and will attempt to understand qualitative potential of berries after a heated treatment. To conclude, this project aims to complete the lack of knowledge on aromas and precursors sensitivity to temperature. Alternatively it is to give levers/tools for viticulture adaption facing to climate change.

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Keywords **:** grape, vineyard, *Vitis vinifera*, Cabernet Sauvignon, Sauvignon Blanc, microclimate, aromas, aromas precursors, temperature, climate change

# Multi-seasonal effects of warming and elevated $CO_2$ on grape and wine composition of mature, field grown Shiraz grapevines

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Increasing temperature has long been associated with negative impacts on important grape and wine quality attributes such as colour. The primary driver of temperature elevation is higher atmospheric carbon dioxide ($CO_2$) concentrations. The effect of $CO_2$ on plant composition varies widely depending on plant species and cultivar and is expected to have a wide-ranging impact on grape and wine composition. Field-based studies of the effects of elevated $CO_2$ on grape and wine composition have been conducted in the past, but have not previously been combined with the control of air temperature. The combined effects of elevated $CO_2$ and warming on grape and wine composition are not fully known and are critical for adaptation to climate change.

To investigate this, open top chambers (OTC) that used an active heating system to elevate temperature by 2$^o$C above ambient (eT) were installed in a mature Shiraz vineyard managed to current commercial practice. The OTCs were combined with a system to simultaneously elevate $CO_2$ ($eCO_2$) around grapevines in the chamber to 550 ppm. The experiment consisted of a complete factorial combination of ambient/elevated $CO_2$ and ambient/elevated temperature. An untreated open air (*i.e.* chamberless) control was also included. The experiment was laid out as a randomised complete block design, with four replicates. The effects of $eCO_2$ and warming on vine growth and physiology are described in a partner presentation.

Measurements made on grapes sampled at harvest in the first two seasons suggest variable grape composition responses. For example, grape phenolics in the first season were decreased by eT, but were increased by eT + $eCO_2$ in the second season. More subtle differences were observed in tannin and anthocyanin composition and pH and titratable acidity in the free run juice. Wine made from the first season's grapes had distinct sensory properties that could be related to warming.

Seasonal influences are obviously important, particularly as the temperature elevation is relative to ambient. But, as the vines acclimatise to the elevated atmospheric $CO_2$ and warmer temperatures, more consistent responses are likely to come to the fore over coming seasons. Indeed, differences in the levels of non-structural carbohydrates are already becoming apparent (see partner presentation), and flow on effects on shoot vigour *etc* can be expected. The importance of those flow on effects in terms of the development of adaptation strategies remain to be determined.

# Grape model implementation for studying the impact of climate change

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In recent years, the most traditional wine-making regions have been profoundly influenced by climate change in terms of grape growth, development and yield. Indeed, the interaction between changes in mean climate and variability expected in future scenarios will play a fundamental role on grape yield and quality. In this case, higher temperatures are related to a shorter duration of the grape growth cycle and lower yields. Moreover, the effect of heat stress during flowering influences the next phenological stages in terms of reduced berry size and number.

In this context, crop simulation models can be considered useful tools for evaluating the non-linearity of the interaction between mean climate change and extreme events on crop growth and development. On this basis, the simplified grape model proposed by Bindi et al. (1997) was updated to include the effects of mean climate and climate extremes on yield and implemented on BioMA (Biophysical Model Application) software platform. BioMA simulation environment may be an important tool for using the model in operational applications and for running it in target areas. Additionally, the modular structure of the code allows an easier maintenance of the crop domain and makes simpler the introduction of new implementations. The new processes implemented consider i) the use of chilling unit requirement to improve the estimation of dormancy release and bud-break date; ii) heat stress effect during grape flowering phase in order to consider the influence of high temperatures on fruit set and final grape yield.

In this case, chilling unit model was tested on ten grape varieties using data from the northern part of Italy. A better accuracy for bud-break date is showed in calibration and validation for the new model ($r=0.87$; $r=0.62$) in respect to the original one ($r=0.82$; $r=0.48$). Moreover, a relationship was found for defining the simulated trend between temperature and fruit set ($r=0.69$; $p<0.05$).

On these premises, future steps will concern i) the introduction of nitrogen balance that considers nitrogen dynamics and uptake in response to higher temperature and water stress conditions and ii) biomass partitioning in response to abiotic stress.

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# Optical and SAR satellite images potential for vineyard monitoring in the climate change context

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The mitigation of climate change effects over vineyards area represents an important stake for viticulture sustainability. However, it requires a fine spatial knowledge of terroir variability and practices impacts on grapevine phenological cycle. Remote sensing appears to be an interesting tool to study both of these aspects. Until now, studies revealed the potential of optical remote sensing for mapping soil spatial variability, vine vigour and yield estimation at plot and inner-plot scale (Hall et al., 2002). Some researches introduced the study of grapevine phenological cycle at large and fine scale using optical or C-band SAR images (Cunha et al., 2010; Fraga et al., 2014; David Ballester-Berman et al., 2012).

The aim of this work is to monitor grapevine phenology and its control over a viticultural landscape in Mendoza (Argentina) by using in synergy a very high resolution spatial optical and SAR dataset. Mendoza study area is one of the most extreme viticultural zone: high temperatures and strong water deficit. In the climate change context of stronger water deficit, higher temperatures and more storms in summer, a detailed knowledge of terroir functioning over the phenological cycle is required. This will leads to define the best adaptation strategies at short/mid term. All the data were acquired during the 2014-2015 campaign. A ground database was built leading to a deep knowledge of local climate variability, soil types and viticultural practices among 400 ha of vineyards. The grapevine phenological cycle was followed through LAI (Leaf Area index) estimation by hemispherical images, phenological records at flowering, veraison and maturity monitoring. The harvest dates and yields of each parcel were also recorded. Satellite images are composed of 6 Dual pol TerraSar-X images (HH/VV), 5 Pléiades images (Bundle mode) and 12 Landsat-8 images (OLI/TIRS).

The preliminary results of the multivariate and multitemporal analysis reveal the interest of using both optical and SAR images to monitor grapevine development. Biophysical variables (LAI, Fcover, NDVI, TSAVI…) derived from optical data and SAR parameters ($\sigma^0$HH, $\sigma^0$VV, Shannon Entropy…) provide relevant metrics to emphasize the spatial and textural structure of the vineyards and their temporal profiles, which leads to a better understanding of the phenological variability over a wine-producing area.

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# Influence of elevated temperature on fruit yield and grape composition of thirteen Tempranillo grapevine accessions differing in cycle length

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The increase in air temperature projected within a climate change scenario can influence grape ripening and must composition. In this regard, grapevine genetic diversity may be exploited to maintain grape and wine quality under future warm conditions. The aim of this study was to assess the effect of elevated temperature on the timing of phenological development, fruit yield and grape composition of thirteen accessions of Tempranillo grapevine (*Vitis vinifera* L.), which differ in their cycle length. Tempranillo selections 86, 1052, 336, 518, 501, 349, 280, 825, 807, 814, 318, 56, and 1084 (Government of La Rioja, Spain) were grown as own-rooted fruit-bearing cuttings under greenhouse conditions. Two temperature regimes (24ºC/14ºC or 28ºC/18ºC, day/night) were applied from fruit set to maturity. Plant phenology was determined as the number of days that elapsed between fruit set and veraison, and between veraison and maturity. Fruit yield, and technological and phenolic maturity parameters were determined at ripeness (total soluble solids, TSS, between 21 and 23ºBrix). Grape pH, TSS content and skin total anthocyanins were also analyzed at pre-veraison, mid-veraison, two weeks after veraison and ripeness. The studied accessions of Tempranillo significantly differed in the number of days that elapsed between fruit set and maturity (differences of up to 34 days). Accessions 349, 807, 814 and 1084 had the longest cycles, whereas 501 and 518 are among those with the shortest ones. These differences were mainly observed in the elapsed time from veraison to maturity. Elevated temperature reduced in 13 days, on average, the time to reach maturity (from fruit set), and had a greater influence before the onset of maturity (elapsed time from fruit set to veraison) than after (elapsed time from veraison to maturity). Bunch weight, berry size and number differed among accessions. By contrast, elevated temperature only affected significantly berry size, decreasing its caliber and weight. Regarding technological maturity, grapes grown under elevated temperature had significantly lower titratable acidity, malic acid and tartaric acid concentration, as well as higher pH values, for the same concentration of TSS (around 23º Brix). Differences among accessions were only significant for malic and tartaric acids. At maturity, the concentration of total anthocyanins in the must was significantly different among accessions. Curiously, accessions 807 and 1084, characterized by a long cycle, had the lowest levels of must extractable anthocyanins. Interestingly, elevated temperature did not significantly modify must extractable anthocyanins in eight out of thirteen accessions. In general, elevated temperature decreased must colour intensity and increased hue (tonality). The evolution of pH, TSS and total skin anthocyanins throughout grape ripening will be also analyzed.

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# Climate change effects on phenology and yield of three white varieties cultivated under rainfed conditions in the Penedès DO (NE Spain)

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This work investigated the relationship between vine phenology and production and climate in vines of NE Spain as well as the potential effects of climate change. The study was carried out in rainfed vineyards in the Penedès region, NE Spain. The main soil types are *Typic Xerorthent* and *Typic Calcixerepts* and soil is bare most of the time. Vines were planted with Chardonnay, Parellada and Macabeo varieties in a pattern of 3.1m between vines and 3.3 m between rows; vines are orientated NNE-WSW on an average slope of 9%. Daily climatic data [maximum (Tmax) and minimum temperature (Tmin) and precipitation (P) ] recorded at Els Hostalets de Pierola (2.5 km far from the studied plot) were analysed for the period 1996 to 2012 as well as the dates corresponding to budbreak (BB), bloom (BL), veraison (V) and harvest (H) for both varieties and for the same period. The relationships between the phenological dates and climate variables were analysed using a multiple stepwise regression. Changes in climate were simulated using the 10 models integrated in the Coupled Model Intercomparison Project (CMIP5) and for two Representative Concentration Pathways (RCP) scenarios – RCP4.5 and RCP8.5 for 2050 and 2070. Changes in the phenological dates and yield related to climate change under both scenarios were evaluated.

The phenological dates differed between varieties up to 28 days, with high variability among years with different climatic conditions. The three varieties responded in different way to temperatures recorded between phenological stages. The variables that showed higher influence on phenology were the average Tmin previous to BB, between BB and BL and between BL and, as well as Tmax between BB and BL. The results showed, that phenology of Chardonnay was the affected in lesser magnitude than Macabeo and Parellada, being the advance of veraison and harvest higher than those of bloom for the three varieties. The projected change sin temperatures could produce under the scenario RPC 4.5 an advance of veraison of about 4.7 days for Chardonnay, 6.1 days for Macabeo and 7.3 days for Parellada for 2050, and up to 5.8, 10.3 and 8.3 days respectively for 2070. The projected changes in harvest dates could imply advances of about 7, 9.7 and 15 days for 2050 and 8.4, 10.4 and 16.2 days for 2070, respectively for the three varieties. Under the scenario RPC8.5, the predicted trends of maximum and minimum temperatures for the RPC 4.5 scenario gave rise phenology advance about 30% higher for the scenario 2050 and about 50% higher for 2070. The increase of temperature during the growing season could also generate a decrease in yield. Based on the observed relationship between yield and the average Tmax during the growing season and the temperature trends, the yield for Chardonnay could be reduced up to 35% for the scenario RCP 4.5 and up to 45% for under RCP8.5. For Parellada and Macabeo, the yield reduction could be higher than 57% and up to 70%, respectively, for the scenario 2070 under RCP 8.5.

Keywords: bloom, budbreak, grape yield, RPC4.5, RPC8.5, temperature, veraison.

Acknowledgments: author thanks the METEOCAT by the climatic data and vinegrowers for the vine informations.

# Expected Growing Season Temperature Increase in Eger wine district of Hungary Based on Regional Climate Modelling

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Changing climatic conditions of Hungarian wine growing districs were studied previously on a regional scale. Our goal was to give a more accurate estimation of the growing season's temperature conditions in the vineyards of Eger region (Northeastern Hungary) for the middle and the end of the 21st century, focusing on two main parameters: the Heliothermic Index and the Cool Night Index.

Daily minimum, maximum and mean temperature data series of three different sources were used: 1) automatic meteorological stations located in the vineyards, 2) E-OBS gridded database, 3) PRECIS regional climate model outputs. The calculations were interpolated to one grid cell which represents the entire region.

Daily mean temperature showed an increase of 0.5 °C in the past 50 years. Heliothermic and Cool Night Index values also increased. The vineyards' meteorological stations showed positive anomalies in Heliothermic Index and Cool Night Index values compared to the E-OBS dataset.

For the 21st century, the climate model outputs suggest further decrease of the number of days with low temperature values and a remarkable increase of the number of days with high and extreme high temperature values, average minimum, maximum and mean temperature values, Heliothermic Index and Cool Night Index values. The average daily mean temperature is projected to be 14.7 °C at the end of the 21st century, which means an increase by 5.1 °C compared to the 1961-1990 reference period. For the middle of the 21st century results predict an average value of 2485 °C for the Heliothermic Index, and 14.1 °C for the Cool Night Index in an "average" vineyard. For the end of the 21st century the projected average values of the Heliothermic Index and Cool Night Index are 2944 °C and 16.8 °C, respectively.

# Estimating the Impact of Climate Change on Temperate, Subtropical and Tropical Grape Growing Regions in Brazil

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Viticulture for table grape or wine production in Brazil was historically established in the extreme South of the country, in temperate climate. More recently, new producer regions appeared in South, Southeast and Northeast of the country, including subtropical and tropical type of climate in the production scenario. Some studies characterized the Brazilian climate of production regions in all types of climates. The potential impact of climate change on different grape growing regions of Brazil needs to be evaluated to project investments, considering challenges and mitigation actions, for the development of table grape and wine production in Brazil.

This work had the goal to estimate the potential impact of climate change related to viticulture potential on different producing regions of Brazil that concerns temperate, subtropical and tropical types of climates.

Thirteen producing regions in Brazil were studied: Campos de Clima da Serra, Serra Gaúcha, Serra do Sudeste and Campanha in the state of Rio Grande do Sul; São Joaquim and Rio do Peixe Valley in Santa Catarina state; Northwest region of Paraná state; Northwest region, Jundiaí and São Miguel Arcanjo in São Paulo state; North and South regions of Minas Gerais state; and, São Francisco Valley in Bahia and Pernambuco states. The methodology used a climatic database series 1961-1990 as baseline period (Conceição et al., 2012). PRECIS (Low and High) and ETA (Low, Midi and High) models of climate change were run for scenarios in 2025 and 2055. The Heliothermal Index (HI), Cold Night Index (CI) and Dryness Index (DI) of the Geoviticulture MCC System and the Zuluaga Index, were calculated. Indices for regions with viticultural potential to produce more than one cycle/harvest per year were calculated also for autumn-winter period of the year. The indices values, mapped in GIS for the total area of each region, corresponds to the average of the region.

The results quantified an important climate change in all producing regions. Some will change MCC climatic groups. Concerning classes of viticultural climate for CI, cool/temperate nights tend do became temperate/warm nights. Regions with Cool class for HI will tend to disappear in a long-term period in Brazil. Concerning Dryness Index, the study detected particular scenarios in each region, consequence of the water balance in the climate change context. The Zuluaga index showed that, in some regions, the potential for viticulture phytosanitary problems would rise with climate change.

This climatic zoning will help to understand how to work on actions to mitigate the potential impact of climate change on a medium and long-term period, in different scenarios for grape growing and winemaking in Brazil.

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# "HeatBerry": sensitivity of berry ripening to higher temperature - berry metabolism

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Aromas of wine are key components for quality and value, but recent observations show they are usually negatively influenced by climate change in most viticultural areas. The presence and amounts of aromas or aromas precursors in the mature grape berry are also known to be partly determined by thermal conditions during the ripening period. On the other hand, simulations of the impacts of climate change in temperate or Mediterranean-like areas indicate that the main challenge for viticulture will result from much hotter ripening conditions. The aims of the "HeatBerry" project are therefore to improve the understanding of secondary metabolism leading to aromas precursors and aromas in grapevine berries and to assess its sensitivity to temperature, mainly for higher temperature.

Manipulations of grape microclimate by the passive heating provided by open top screens and localized greenhouse effect are an effective way to quantify the response to temperature in actual field conditions, as long as other factors remain identical (Sadras et al., 2009, 2012). Field experiments using open top polycarbonate screens were conducted on Cabernet Sauvignon and Sauvignon Blanc vines during the 2014 and 2015 seasons in a Bordeaux vineyard, with continuous control of air and berry temperature and solar radiation and occasional control of growth and water status. The experiment was carried out from bunch closure to maturation and berries were sampled periodically until the post-maturation stage; microvinifications were also realized from mature berries. The results showed that the whole plant status was not changed by the heating treatment while a 1-3 °C increase in berry temperature was observed. Sensory analysis of the wines showed that bitterness, fullness and fruity character were influenced by the heating treatment (see Drappier et al., this symposium). Therefore, this moderate heating of the berries, which lies within the expected range of temperature increase associated with climate change, might be sufficient for significant effect on aromas metabolism.

At least for some of the aromas and aromas precursors that are now well characterized in the Cabernet Sauvignon and Sauvignon Blanc varieties, the project will attempt to work out the metabolic network and key stages or factors which are actually sensitive to temperature. Analysis of metabolic pathways will involve refined techniques in the biochemistry, gene expression and transcriptome areas followed by a modeling approach.

Acknowledgements: We thank the Aquitaine Regional Council (CRA) and Interprofessional Bordeaux Wines Council (CIVB) for funding the HeatBerry project and Bordeaux-Adelaide-Geisenheim (BAG) alliance and Bordeaux Vine and Wine Institute (ISVV) for networking and initiating the project.

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# *SESSION 5 : Ecophysiology for climate change*

## *ORAL*

# Grapevine and climate warming: Duravitis program opens new breeding strategies for temperature adaptation

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The performance of grapevine, including productivity and wine quality is highly dependent on climate. In the long term, genetic improvement is one major strategy that will support sustainable grape production systems facing the announced climate changes. Unfortunately, the lack of knowledge about the genetic mechanisms of grapevine adaptation to temperature limits the efficiency of genetic improvement. In the last 5 years, we have performed an interdisciplinary program aimed to: i) characterize the impact of an increase of temperature, sensed by the entire plant or individual bunches, on the development and functioning of the plant (organogenesis, biomass variation, berry metabolism), ii) identify the molecular mechanisms regulating the response of vegetative and reproductive systems to heat stress and ii) develop tools to map QTLs of plant and berry developments in duly controlled, stable, and contrasting environmental conditions.

Performing high-throughput genomic analyses combined with the use of innovative experimental models (fruiting cuttings, microvines), was critical to decipher the ecophysiological and molecular mechanisms involved in the response of the vine to high temperatures. Temperature exerted strongly different effects on the kinetics of vegetative or reproductive developments The data revealed the central role of carbon balance in the plant response to thermal stress with critical effects on the distribution of biomass within the plant and also changes in the primary (sugars, organic acids) and secondary (phenolic compounds) berry metabolisms. Day and night transcriptomic and proteomic signatures associated with heat stress in grapes were revealed, highlighting key players of the temperature response in grape. Ultimately, tools were developed for breeding new varieties adapted to warm temperatures including: i) a framework of Mivrovine phenotypic analysis, ii) stable QTLs of grapevine development under various temperatures and iii) innovative methodologies (RNAseq, proline assay and embryo rescue).

Capitalizing on these knowledge and tools, we are starting a new program to select cultivars with limited accumulation of sugars in regard to qualitative compounds from either primary (organic acids) or secondary metabolism (pigments, aromas).

**Acknowledgments:** This work was supported by the ANR-Genopole (project ANR-2010-GENM-004-01), the foundation Jean Poupelain, the CNIV (Comité National des Interprofessions des Vins à appellation d'origine) and the CIVB (Comité Interprofessionnel des vins de Bordeaux).

# A Combination of Phenotyping, Genetic and Physiological Approaches to Guide Breeding for Efficient Water Use in Grapevine

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Water scarcity associated with climate change particularly threatens the sustainability of viticulture in most cultivated, drought prone areas. Breeding grapevine for reduced water use and maintained production (that is high water-use efficiency) is therefore of major interest. This requires a comprehensive knowledge of the physiological impacts of drought which are the most influential on yield and quality. Special attention should be paid to those mechanisms involved in the regulation of water status in plant tissues as the primary parameter affected by drought. Transpiration rate, which has major influence on plant water status, together with water-use efficiency, therefore require special attention in breeding programs.

To progress on the determinism of transpiration rate and water-use efficiency in grapevine, we used a F1 progeny made of 188 genotypes from a cross between two widespread cultivars, Syrah and Grenache, well-known for their contrasted water use. We showed the benefits of combining quantitative genetics (for QTL detection) and physiological experiments to study this population both in the vineyard and on potted plants. On the one hand, we developed an original experimental design in the field coupled to geostatistical modelling to take into account the spatial variability of soil water status inherent to vineyard conditions. This helped to identify significant genetic variability for the traits of interest. On the other hand, we combined powerful phenotyping tools on potted plants (high-throughput platform and controlled chambers) to control water deficit conditions and improve QTL detection.

First, we found evidence that a dual physiological mechanism controls the decline of leaf water status under drought with a key role for plant hydraulic conductance beside that of stomatal control of transpiration. Contrasted combination of these two controls may lead to more or less efficient maintenance of leaf water status in response to soil drying (i.e. iso- or anisohydric behaviour). An indirect role of abscisic acid on stomatal conductance was also identified, mediated by the downregulation of leaf hydraulic conductance, with a genetic variability which correlated with genetic variation in iso- or aniso-hydric behaviour. We then revealed wide genetic variations in nocturnal transpiration, which correlated with variations in whole plant water-use efficiency (WUE), and identified corresponding genetic and physiological determinants. Lastly, we showed some consistency between QTLs detected for daytime WUE in pots and in the vineyard.
Beyond the potential interest of the QTLs detected in this study for breeding prospects, this work demonstrated the interest of quantitative genetics to shed light on ecophysiological and physiological processes.

Key-words: Water deficit, QTL, high-throughput phenotyping, isohydric, transpiration, hydraulic conductance, abscisic acid, water-use efficiency, night time transpiration.

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# Predicting the effects of drought and climate change on the composition and extractability of flavonoids in Cabernet Sauvignon

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The purpose of the study was to monitor berry development as a function of site, vine water status and climate in order to improve our understanding of the role played by climate change on secondary metabolites relevant to wine quality. 35 wineries, consisting of 75 vineyard blocks, mainly located within the Napa Valley were monitored throughout the 2015 growing season. Across the studied sites, there was a large difference in climatic conditions, ranging up to 700 growing degree days. This large difference in heat accumulation profiles, as well as heat events, in the local area allowed us to better understand the change in phenolic concentration, composition and extraction profiles over a range of pedoclimatic areas. Vine water status was measured throughout the season using sap flow sensors within the berry sampling area. For each site, berry samples were collected at five times between veraison and commercial harvest. Skin and seed exhaustive extractions (2:1 acetone:water) were done after the pulp was removed from the berry and the skin separated from the seed. Partial extractions of berries was done on crushed whole berries in a 14% v/v ethanol solution containing 100 mg/kg of SO2 in order to develop an understanding of phenolic extractability over the space-time-climate continuum. Extracted phenolics were monitored using four separate HPLC methods in order to provide information on low molecular mass phenolics as well as tannin concentration, composition and activity. A discussion of climate change impact on premium wine production regions is given in the context of the variation in phenolic chemistry observed in this study.

Keywords : extractability of flavonoids ; Cabernet Sauvignon; drought; polyphenols maturation kinetics

# Summer and autumn, not winter, matter in dormancy of the grapevine

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It is well-known, that while grape cultivars may be grown in low latitude climates, especially if at altitude (Possingham, 2008), the normal phenology is greatly disturbed. Here we have begun a preliminary assessment of cultivar performance in medium and low latitudes as a surrogate for a warming climate, choosing two cultivars: Flame Seedless and Merlot. We included Merlot as a standard so that we could match our observations to the seminal work on bud dormancy and state by Pouget (1963).

Our observations show remarkable differences in state and dormancy according to the location of cultivation. Bud state has been assessed as the duration from excision and planting to bud emergence, water content, cell cycle state fraction (S, G …) and respiration.

In agreement with previous analyses, Merlot exhibited near synchronous entry into a state of deep 'summer dormancy' in mid-summer (Pouget, 1963). This became largely attenuated by late autumn. Bud moisture content however remained low until immediately prior to field date of bud burst (EL4, Coombe, 1995). Flame Seedless exhibited delayed entry into 'summer dormancy' did not become as resistant to re-establishment of growth as did Merlot, nor did the buds become as desiccated. These differences were climate correlated.

Remarkable changes in bud respiration and especially of respiratory quotient were noted through the resting phases of the buds which suggest that novel metabolic processes may be involved (the buds are normally hypoxic, Meitha et al., 2015).

These data will be discussed in terms of the manner in which climate-change may affect the phenological cycle and productivity of the grapevine and the processes that may underlie the observed disruption of the cycle in warm or low latitude climatic zones.

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# How do rootstocks control scion water use efficiency ?

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Water is the main limiting factor for yield in viticulture. Improving water use efficiency (WUE) in viticulture is an important issue in the context of climate change. Genetic variability of WUE in grapevine is partly due to rootstocks (Iacono et al., 1998). The objective of the present work is to analyze the genetic determinism of shoot growth and WUE induced by the rootstock under water deficit conditions.

A mapping pedigree consisting of 138 F1 individuals, derived from the inter-specific cross of *V. vinifera* Cabernet Sauvignon × *V. riparia* Gloire de Montpellier, was used as rootstock. Cabernet-Sauvignon was the scion grafted on each genotype of this population. The experiment was carried out in pots, in a greenhouse. Water deficit intensity was evaluated daily by weighing each pot individually with a 150 scale platform. Irrigation was applied daily in order to keep all the pots at the same water content. After 10 days without any water deficit, a progressive water limitation was applied for 10 days, then followed by a stable water deficit stress for 15 days. Pruning weight, root and aerial dry weight and transpiration were recorded during three years. Transpiration efficiency (ratio between aerial biomass and transpiration, TE) was calculated and $\delta^{13}C$ measured in leaves formed during the period without any water deficit and those formed during the period of stable water deficit.

A large variability was observed within the studied population. QTL analysis was then performed for all the traits studied. These results demonstrated that growth regulation of the scion by the rootstock is determined genetically. The genetic architecture of biomass accumulation and water use efficiency were at least partially independant. WUE-related traits were mediated exclusively by rootstock genetic variability, rendering the model more complex. No QTLs common to TE and $\delta^{13}C$ were identified, supporting the hypothesis of independent genetic architectures for these two traits. This suggests that interpretation of $\delta^{13}C$ is not straightforward to study when trying to select plants with a high WUE (Condon et al., 2004), particularly in grapevine rootstock breeding programmes (Flexas et al., 2010). The QTLs detected for TE in multi-year and multi-water status analyses were colocalized, suggesting that the genetic architecture for TE is stable in all environments and thus potentially easier to use for breeding purposes.

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# Will grapevine pathogens adapt to climate warming? Temperature reaction norms of life-history traits in grapevine downy mildew

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Plant pathogens are a significant constraint to agriculture and are challenged, along with their hosts, to climate changes. While the influence of climate on pathogen impacts on their hosts have been reviewed (Garrett et al., 2006), pathogen adaptation to climatic changes is still unclear. However, the adaptive potential of plant pathogens to abiotic conditions is one of the most important predictors of the magnitude of climate change impact on agro-ecosystems (Garrett et al., 2006). Despite the applied importance of studying the response of grapevine pathogens to climate warming, we still lack experimental data on current adaptation to temperature and pathogen's evolutionary potential facing climate changes.

We conducted a common garden experiment using populations of the biotrophic grapevine pathogen *Plasmopara viticola* collected on Chardonnay in northern and southern vineyards showing contrasted climatic conditions. Clonal replicates of 70 genetically distinct isolates were assessed for aggressiveness (quantitative traits of pathogenicity) at 12°C, 18°C and 24°C.

We found highly significant phenotypic plasticity to temperature of northern and southern populations, significant genetic adaptation especially in the cold environment and significant 'genotype x temperature' interaction. We analysed reaction norms for a range of quantitative traits of pathogenicity and performed a quantitative genetic analysis ($Q_{ST}$ vs. $F_{ST}$) to understand the evolutionary processes underlying these results. Our findings show that grapevine downy mildew has a high genetic variation with high plasticity for temperature, which is therefore unlikely to limit its adaptation to climate warming.

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# *SESSION 5 : Ecophysiology for climate change*

## *POSTER*

# Hydraulic connections: Modeling shoots hydraulic architecture of grapevine to apprehend leaf-scale gas exchanges and WUE in complex canopies

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Although grapevine (*Vitis vinifera*) is reputed for its high adaptability to low water availability conditions, global warming and the resulting aleatory water deficit events has raised concerns in developing new training systems adapted to the changing climate context (Medrano *et al*., 2012). Such training systems are thus called to optimize water use while preserving the production quantity and quality.
In this study, the Functional-Structural Plant Models (FSPM) approach was used to estimate the grapevine gas exchange dynamics resulting from different training systems under water deficit conditions. The cornerstone of this work is the simulation of the stomatal conductance $g_s$ at the leaf scale as a function of both the local micro-climate conditions and the plant/soil water status.

$g_s$ is simulated as a function of the net assimilation rate ($A_n$), vapor pressure deficit (VPD) and inter-cellular $CO_2$ concentration ($C_i$) as described by Leuning (1990). The soil/plant water status effect on $g_s$ is accounted for by relating $g_s$ to the leaf water potential $\Psi_L$ according to the empirical approach (Damour *et al.*, 2010). $\Psi_L$ is related to the collar water potential $\Psi_C$ (which represents the averaged soil water potential in the root zone) using three methods of different degrees of complexity: (1) $\Psi_L$ is considered uniform among all the leaves and is equal to $\Psi_C$ (assuming thus that the stem conductance in negligible); (2) $\Psi_L$ is function of $\Psi_C$ and varies locally with the transpiration flux density (E) but no hydraulic connection is considered between the leaves; (3) $\Psi_L$ is function of $\Psi_C$ and E with leaves being hydraulically connected using a complete description of the shoot hydraulic structure of the plant.

The results of this study aims at providing answers to leaf-scale physiological responses of grapevine under water deficit conditions for different canopy structures. The resulting model could be used to assist training systems design to optimize water use efficiency.
Key words: Vitis vinifera, hydraulic architecture, stomatal conductance, water deficit, training systems.

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# Water deficit affects proanthocyanidin composition during ripening in Cabernet Sauvignon (*Vitis vinifera* L.) grape skins

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Controlled water deficit is a common practice in several wine regions mainly because it can influence the chemical composition of the grape with an expected positive effect in tannins content (Kennedy et al., 2002). Additionally, water availability is under threat upon the climate change, particularly in Mediterranean viticulture. Even though water scarcity and its impact on the grapevine physiology have been widely reported, the effect on the proanthocyanidin composition has been barely assessed. Here, we have investigated the effect of water stress on this particular aspect in Cabernet Sauvignon grape skins throughout the ripening process.

The assay was carried out on own rooted *Vitis vinifera* plants cv. Cabernet Sauvignon in a commercial vineyard located in the Maipo Valley, a warmer valley in central Chile, during 2014 growing season. Three irrigation treatments were established. Irrigation treatments begun few days before veraison throughout the season, roughly maintaining midday stem water potentials values of (T1) $\Psi$ = -0.8 MPa; (T2) $\Psi$ = -0.9 MPa and (T3) $\Psi$ = -1.0 MPa.

Chemical analyses for total phenols, tannins and anthocyanins were assessed by spectrophotometry. The fractionation of grape skin proanthocyanidins was made according to their polymerization degree by the use of Sep-Pak $tC_{18}$ cartridges. Mean degree of polymerization and proanthocyanidin composition was performed by acid-catalysis in the presence of phloroglucinol using HPLC-DAD.

Chemical composition of the grape skins was affected by the irrigation regimes. The content of total tannins decreased throughout ripening. Approximately 30 days before veraison, their content increased again, but more pronounced in the most restrictive treatment (T3). The fractionation of proanthocyanidins by Sep-Pak $tC_{18}$ cartridges showed a decrease in the monomeric fraction during ripening. Also, the oligomeric fraction showed an erratic behavior throughout ripening. As for the polymeric fraction, there was an increase during ripening, reaching at harvest a higher concentration of flavan-3-ol polymers in the most restrictive treatment (T3). Only a change in the concentration, but not in the proportion of the different flavan-3-ol fractions, was observed between watering treatments. The grape skins at harvest showed a higher mean degree of polymerization, a higher content of (+)-catechin and a lower content of (-)-epicatechin in T3. Clearly, water deficit increases the phenolic composition of the grapes suggesting an increase in grape quality.

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Kennedy et al. 2002. Effect of maturity and vine water status on grape skins and wine flavonoids. American Journal of Enology and Viticulture, vol. 53, 4, 268-274.

# Regulated water deficit and its effect on phenolic composition and sensory characteristics of Cabernet Sauvignon wines

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Regulated deficit irrigation is a common practice in several wine regions mainly because of the well-known effect on wines (Casassa et al., 2015). The effect of climate change could affect water availability, especially in warmer valleys, affecting the grape composition and then the wine quality. For that reason, the influence of controlled water deficit on phenolic composition and sensory characteristics in Cabernet Sauvignon wines were investigated in a warm viticultural region from Chile.

The wine was obtained from grapes of own rooted *Vitis vinifera* L. plants cv. Cabernet Sauvignon subjected to three irrigation treatments which begun few days before veraison, throughout the season, roughly maintaining midday stem water potentials values of (T1) $\Psi$ = -0.8 MPa; (T2) $\Psi$ = -0.9 MPa and (T3) $\Psi$ = -1.0 MPa. The commercial vineyard was located in Maipo Valley, and the assay carried out during the 2014 growing season.
Chemical analyses for total phenols, tannins, anthocyanins, color intensity and CIELab coordinates were assessed by spectrophotometry. The fractionation of proanthocyanidins was made by the use of Sep-Pak $tC_{18}$ cartridges. The anthocyanins and proanthocyanidin composition was carried out with HPLC-DAD. Temporal dominance sensation (TDS) and descriptive analysis was performed using a sensory panel consisting of 13 judges.
Chemical composition of wines was affected by the irrigation regimes. The wines from the most restrictive treatment (T3) showed a higher concentration of total phenols, total tannins and total anthocyanins with differences in the chromatic properties. T3 wines resulted in a higher color intensity, lower L* value and higher C* value. Regarding to the anthocyanin composition, the most restrictive treatment resulted in a higher concentration in glucosylated anthocyanins such as delphinidin-3-glucoside, peonidin-3-glucoside and malvidin-3-glucoside as well as the acetylated anthocyanins cyanidin-3-acetilglucoside, petunidin-3-acetilglucoside and malvidin-3-acetilglucoside.
The fractionation of proanthocyanidins by Sep-Pak $tC_{18}$ cartridges showed that the most watered treatment (T1) presented a higher content of flavan-3-ol monomers. Still, only a change in the concentration, but not in the proportion of the different flavan-3-ol fractions, was observed between treatments. The wines from the most restrictive treatment showed a higher mean degree of polymerization, a lower content of (+)-catechin and a higher content of (-)-epigallocatechin. The differences in chemical composition influence the sensory properties of wines. Wines from the most restrictive treatment presented more red fruits, less acid and higher mouth-feel properties. Our results suggest that water deficit increase the phenolic composition, increasing the sensory quality of wine.

Acknowledgments: Fondecyt Postdoctoral Grant N° 3140269 (Conicyt-Chile)

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# Irrigation effects about must´s aromatic compounds of cv Albariño – Galicia (Spain)

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The interannual climate variability in the Rías Baixas AOC has generated the need to explore new management strategies (irrigation) that allow managing water stress in a vigorous variety as Albariño. The lack of previous studies on the effects of irrigation (Fandiño et al, 2012; Martinez et al, 2013) and the aromatic components of Albariño (Zamuz and Vilanova, 2006; Vilanova et al, 2007) as a whole, have led us to propose a study about the effects of the irrigation on the main free aromatic components of Albariño must.

During 2014, it was performed the monitoring of cv Albariño, in a commercial plot area from O Rosal (Rías Baixas AOC), in Fornelos (Pontevedra). The vineyard was planted in 1996 on standard 110-R with trellised vines. The plantation frame was 3 m between streets and 2 m between plants (1667 plants by ha) and the rows were oriented east-west. The irrigation was performed with two drip irrigation systems: surface (DI), with two emitters per plant (4 L $h^{-1}$) and subsurface (SDI) with 2 L $h^{-1}$ per lineal meter. In total, have been applied irrigation in 13 days, with 4 hour daily (DI-66mm, SDI-33mm). Two replicates per treatment were established, including a control treatment (Rainfed), with 7 plants per block and repetition. During the harvest, the production parameters were determined. In addition, must samples were obtained for the determination of grape quality parameters (GAP, Total acidity and pH) and the main aromatic families using GC-FID and GC-MS, on the premises of INIAV-IP (Dois Portos-Portugal). Prior to aromatic analysis has been made liquid-liquid extraction, using the standard 4-nonanol (Botelho, 2008; Botelho et al., 2010).

The results have shown no significant differences among irrigation treatments due to the important rainfall in 2014 (724 mm) and have not been exceeded values of steam-leaf water potential of -0.5 MPa. However, high values were obtained in SDI treatment for three aromatic components, suggesting that in years with extreme weather conditions, the irrigation strategy could have influence in the flavor profile obtained in each treatment.

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# Grapevine root growth under water stress and its relationship to root water uptake

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It is known that plant growth and development are greatly influenced by water availability and uptake. In the context of global warming, viticulture is increasingly focused on developing new rootstocks that facilitate adaptation to drought. Water stress is known to modify root structure and function, but little is known regarding how genotypes differ in their ability to maintain water uptake and root growth under stress. Physiological, anatomical, and genetic characteristics of water transport across roots were studied in two rootstocks considered as low-medium (RGM, Vitis riparia) and highly (110R, Vitis berlandieri x Vitis rupestris) drought resistant. Rootstocks were grown in rhizotrons under well-watered or water-stressed conditions, and the growth rate of individual roots, changes in anatomical structure, as well as aquaporin (VvPIP) gene expression were evaluated.

Individual root growth rate is very plastic and although water stress reduces root growth on average, individual root growth rate is incredibly variable. We observed growth rate differences between cultivars under well-watered conditions with the roots of 110R having a faster growth rate than RGM. However, under water deficit conditions these differences collapsed and the roots from both genotypes grew at a similar speed associated with a higher degree of suberization in exodermis as well as endodermis. The expression of seven VvPIP genes was analyzed, among which VvPIP1;1 and VvPIP2;4 were the most highly expressed. We consistently observed that the expression of VvPIP1;3;5 and VvPIP2;1 were genotype-dependent. VvPIP2;3 and VvPIP2;4 were influenced by drought treatment but in an opposite direction. VvPIP2;4 was correlated with root growth rate but in a genotype specific fashion. Further experiments need to be conducted, especially in combination with changes in root hydraulic conductivity in order to provide a better understanding on how root structure, growth, and water uptake respond to water stress and contribute to drought tolerance.

# Non-invasive NIR spectroscopy for in-field grapevine water assessment

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The most important wine regions in the world are located in areas which are seasonally dry with high evaporative demand and low water availability. These conditions are expected to be accentuated in the context of climate change and global warming. Increased temperatures and heterogeneous precipitation patterns are forecast, and optimized irrigation emerges as one of the main strategies to steer quality grape production. In this framework, the implementation of optimized irrigation based on fast, reliable, comprehensive indicators, becomes a priority in agricultural research worldwide.

NIR spectroscopy is being increasingly used to better understand biological systems, by means of studying distinctive water absorption bands. In this work, NIR spectroscopy has been tested under field conditions to explore its capability to assess grapevine water status non-invasively, from a moving vehicle.

The trial was carried out in an experimental Riesling vineyard located close to Geisenheim (Germany) during season 2014. Two different grapevine water status regimes (stressed and non-stressed) were imposed. At two timings, bunch closure and pre-harvest, contactless measurements of individual leaves of the mid upper part of the canopy, with a NIR spectrophotometer (1100-2100 nm) mounted on an all-terrain vehicle (ATV) moving at 5 km/h were acquired at midday. Measurements with the NIR device were taken from a distance of 25 cm from the canopy. Simultaneously, stomatal conductance ($g_s$) was measured with a porometer on the same leaves monitored with the NIR device. NIR spectra were analysed using partial least squares (PLS) and principal component analysis (PCA). Significant regression models ($R^2 > 0.95$, $p<0.05$) with $g_s$ were built. The first two principal components accounted for 99% of the variation and successfully differentiated the stressed and non-stressed samples.

These first results are promising and evidence the capability of non-invasive NIR spectroscopy to assess the vineyard water status on-the-go, and to become a potential practical tool to drive irrigation scheduling decisions in viticulture in the short term.

Keywords**:** water stress; irrigation scheduling; stomatal conductance; on-the-go.

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# Towards genome-wide association studies under abiotic stress in *Vitis vinifera*

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Genome-wide association studies have proven their efficiency to decipher the genetic determinism of traits of agronomic interest in several plant species. In order to perform such studies in grapevine, we first designed an association panel of 279 *V. vinifera* cultivars from the French National Grapevine Germplasm Collection (Domaine de Vassal, INRA, France). It is composed of three subgroups of 93 cultivars representing the three main genetic pools, which differ in use and geographical origin: wine West, wine East, table East. This panel exhibited a good genetic and phenotypic representativeness of the whole collection. Linkage disequilibrium extent was quite small, 43 Kb for a corrected $r^2$ predicted value of 0.2, emphasizing the need for several dozen thousands markers to achieve powerful genome wide association studies. The second step consisted in dense genotyping of this panel using a 18K SNP Infinium chip and genotyping by sequencing (GBS). While the first method provided useful genotypes at 12K SNPs, about 100K SNPs are expected using GBS with *ApeK*I. Data processing is in progress and this resource will be made available to the scientific community. The third step consists in phenotyping this panel for traits of interest. Vines were planted in a randomized block design at Le Chapitre Research Vineyard (Montpellier SupAgro, France). Traits related to yield (cluster and berry weights) and phenology (maturity date) were measured in three years within the DLVitis program. Then within the Innovine program, grass was used as a cover crop between rows in the whole trial and part of the design was irrigated to obtain two levels of water availability. In addition to yield and phenology traits, berry composition (sugars, acids, anthocyanins, tannins and aromas), pruning weight and adaptation to drought (delta C13) have been measured during two growing seasons under both water availability conditions. This association panel, together with the accumulated data, represent highly valuable resources for genetic studies in grapevine. We are calling for an international collaborative effort to use such a panel in field and greenhouse trials to address questions on adaptation to changing environments.

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# Consequences of elevated temperatures during ripening on the biosynthesis of monoterpenols in grape berries

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The general increase in temperatures due to climate change will impact the temperatures during grapevine ripening not only because an advance of the dates of veraison towards the warmer periods of summer but also because on the same date, the expected temperature will be higher in the future. Simulations using the A1B IPCC scenario showed for the Alsatian grape growing region (Colmar, France) that the increase of mean temperatures during the 35 days after véraison could be approximately 5 °C higher in 2040-2070 for Riesling and Gewurztraminer than in the present years (Duchêne *et al*, 2010). The effect of high temperatures on berry color (Mori *et al*, 2007) or on berry acidity (Kiewer,1971; Duchêne *et al*, 2014) is well documented. Cool temperatures are often empirically associated with enhanced wine flavors (Tonietto and Carbonneau, 2004) but experimental data are very scarce (Bureau et al, 2000).

The objective of the present work was to quantity the effect of elevated temperatures during ripening on the biosynthesis of monoterpenols. The molecules of this family, exemplified by geraniol and linalool, are responsible for floral aromas (Lilly of the valley, Rose, …) found in grapes and wines. Fruitful cuttings of Riesling and Gewurztraminer were grown during three years in growth chambers under two temperatures regimes after véraison: 15°C night/24°C day (Low temperatures, LT) and 21°C night/30°C day (High temperatures, HT). In 2014, genotypes progeny from a Riesling x Gewurztraminer cross were also included in the experiment. The monoterpenol content of the berries was quantified at several time points. In these results, high temperatures impaired the synthesis of linalool, whereas the geraniol content was not affected.

Acknowledgments: these experiments were financially supported the INRA métaprogramme ACCAF in the frame of the LACCAVE Project.

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# Flavonoid interaction with grape chitinase: natural and innovative system for plant defence induction

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Grapevine (*Vitis vinifera* L.) has a high nutritional value in the human diet, since it is a rich source of polyphenols, vitamins and secondary metabolites. Due to their extensive cultivation, grapevine varieties are sensitive to a great number of pathogens. These infections provoke heavy damages to plants and yield losses, finally affecting wine quality. The spread of diseases is generally controlled by applications of chemical pesticides. This controversial use/abuse of pesticides has recently been questioned, particularly under the light of the new nature-friendly trend of agricultural practice management; particular attention has been payed on the pesticide use reduction in favour of the natural plant defence system induction, using natural moieties.

In the present study, an anti-bilitranslocase antibody (anti-BTL Ab), previously used to recognize proteins involved in flavonoid binding (transport), cross-reacted against microsomal proteins, obtained from red grape berry skin. Among all the proteins recognized, by means of 2-DE electrophoresis, a pathogenesis-related (PR) protein was recognized and unequivocally identified by mass-spectrometry analysis as a IV class chitinase. Interestingly, the *in vitro* chitinolytic activity, assessed by both spectrophotometric and fluorimetric assays, was modulated in both commercial pure chitinase (from *S. griseus*) and grape microsomal extract, by two different flavonoids: quercetin (flavonol) and catechin (flavanol). These results highlighted the role of flavonoids not only as antioxidants or direct antimicrobic effectors, but also as modulators of plant growth and plant response to biotic stress. Implication of the present suggestion has been also discussed in the terms of the environment health and reduction of pesticide distribution. (abstract 251 parole)

# How database used to calibrate phenological process-based models can affect simulations under climate change scenarios?

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Phenology is considered as the first biological indicator of this change. Consequently, modeling phenology to provide accurate simulations is essential to correctly predict the timing of development in the future. In this context, the choice of database to calibrate the model can highly impact the results when these models are used under a wide range of climate conditions (Jochner et al., 2013).

In this study we examined the impact of databases and their origin on the accuracy of simulation of flowering and veraison for the grapevine (*Vitis vinifera* L.) under current and future climatic conditions. We compared the results of calibration and cross- validation of several classic phenological models (Growing Degrees Days, Chuine, Sigmoid, Beta function – Wang and Engel and Richardson) for two different varieties (Cabernet Franc and Merlot) using different datasets : 1) Dataset1: a dataset from a network of temperature sensors at a fine scale where phenology was also observed at each of the locations of the temperature sensors (11 to 90 different points); 2) Dataset2: an historical dataset (at least 20 - 30 years) from a plot located in the same area as the network , 3) Dataset3: a dataset obtained from other locations in France (Phenoclim database).

Cross tests of the best model calibrated with each dataset on the other sites were conducted to assess the effect of the choice of database on the model output for each of these stages (flowering and veraison) at different scales. Initial results showed that the database used to calibrate different models could influence model parameters. The best models calibrated with each database will be used to quantify phenology evolution under future climatic conditions on several sites in Europe. PMP software (Chuine et al., 2013) was used to achieve all calibrations and simulations.
Results obtained will further our understanding of how to improve the quantification of uncertainties and to better define which type of database is best suited to calibrate a model.

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# Regulated deficit irrigation on cv. *Touriga Nacional* in the Douro Demarcated Region, Portugal - Physiological responses, productivity and quality effects on grapes

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The weather and climate conditions are crucial for the success of any agricultural system, since they influence the adaptation of the cultures to certain regions, control the quantity and quality in a large scale and contribute, in an ultimate analysis, to the economical sustainability. This way, the understanding on tolerance, resistance and adaptation mechanisms of the plants towards adverse environmental conditions is extremely important, making possible the adequacy of the plants growth conditions and the optimization of the production and quality of several cultures. Douro's Demarcated Region, located in the northeast of Portugal, is characterized by a typical Mediterranean climate, with hot and dry summers, which induce water deficit and thermal and radiative stress, influencing physiological processes, production and quality parameters of the grapevine. These conditions acquire a growing relevance, especially under a climate change impact scenario, as demonstrated in recent studies conducted in the region (Jones, 2013). In southern Europe, increasing in air temperature and decreasing in precipitation is expected, reflected both in lower annual totals as in longer dry periods. While soil water availability is reduced, some physiological processes can be limited or even stopped, canopy photosynthetic capacity is strongly committed and many leaves may become prematurely senescent. Therefore, there is a need to improve the crop water use efficiency, based on physiological indicators, which provide additional information about plant water status. To fulfil this need, an experimental design was conducted during 2015 in a commercial vineyard located in 'Cima Corgo' sub-region (Demarcated Douro Region) including three water treatments: 1) 'Rain-Fed'; 2) 'Regulated deficit irrigation – RDI' (25% of ETc); and 3) 'Regulated deficit irrigation – RDI' (50% of ETc), established since 2002. The aim of this study was to understand better the impac of the different water regimes on the physiology, productivity and quality parameters of cv. *Touriga Nacional*. For this purpose, an evaluation of several parameters was done including predawn leaf water potential ($\Psi_{pd}$), productivity and qualitative parameters such as titratable acidity, pH, probable alcohol and phenolic compounds (total tannins, total anthocyanins and total polyphenols). The results obtained in 2015, a year with scarce precipitation (320 mm between November and August), with several peaks of temperatures, resulting in intense stresses symptoms, showed that, in both RDI modalities, the productivity (Kg/plant) was improved ($RDI_2$: 20%, $RDI_3$: 33%), increasing berry weight, but without compromising quality parameters. Concerning these lasts, RDI modalities did not reduce phenolic compounds (no significant differences were found) and probable alcohol content were enhanced at harvest time.

Keywords **:** Climate change conditions- Water deficit - *Vitis vinifera* - Physiology - Quality - Douro

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# Aromatic discrimination of *Vitis vinifera* L. cv. Sauvignon blanc clone Assessment of aromatic and enological potential

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A significant characteristic of Sauvignon blanc clones most widely planted at present is their early technological maturity. However, in the context of climatic change, they will not be suitable for the production of dry white wines in the early-ripening soils of Bordeaux appellation.

In this context, aromatic potential of Sauvignon blanc clones was monitored during grape ripening from the clone bank of the Chateau Couhins INRA during 2012 and 2013 vintages. Doing so, concentrations of volatile thiol precursors (cysteine *S*-conjugate and glutathione *S*-conjugates), glutathione, and flavanols were determined at several harvesting dates in berries and in must before alcoholic fermentation. Then microvinifications were performed on selected Sauvignon blanc clones that were highly aromatic and later-ripening than the existing commercial standards (19 clones considered in total). Volatile thiols, glutathione, and flavanols content were assayed as well as wine sensory analysis was organized with a professional panel. Results obtained for the two years monitored showed that the clones had specific, stable aromatic and enological characteristics.

Using these clones, decommissioned 20 years ago as too late, now could be a promising approach for adaptation of vine material in a context of climate change.

Keywords: *Vitis vinifera*, Sauvignon Blanc, clone selection, volatile thiols, aromatic potential.

# Physiological and Genetic Control of Vigor in a Ramsey x Riparia Gloire de Montpellier Population.

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Rootstocks can be a valuable tool for viticulturists, conferring numerous advantages, among which vigor control is important. This research studied the F1 progeny from a cross between Ramsey and Riparia Gloire de Montpellier, rootstocks that confer high and low vigor, respectively. We hypothesized that vigor, defined as canopy biomass, correlates with growth rate, leaf area, biomass partitioning, chlorophyll content, and whole plant hydraulic conductance; and that these variables could be associated with genetic markers. We evaluated 138 seedlings from this cross, three replicates each, for 60 days in a greenhouse at UC Davis, California. Each plant was pruned to a single shoot and watered daily. After day 45, selected genotypes were subjected to water deficit (50% of soil water content). Shoot growth rate, leaf area and dry biomass were measured for the complete population, while hydraulic conductance, stomatal conductance, water potential and chlorophyll content were measured for a subset. The progeny showed transgressive segregation and significant differences between small, intermediate and big plants. Correlations between vigor *vs.* growth rate, LA (Leaf Area) and biomass partitioning indices were highly significant ($p=0.00001$). A PCA analysis showed a strong role for *shoot growth rate,* SLA (specific leaf area) and biomass partitioning indices for vigor determination. Under water stress, larger plants showed less specific hydraulic and stomatal conductances, indicating higher sensibility upon drought. Significant QTLs for LA, SLA and partitioning indices were found on chromosomes 1, 4, 16, and 5; accounting for 20% of explained variability for LA, and from 10 to 14% of explained variability for SLA and partitioning indices. For quantitative characters, where positive feedbacks can cause large effects, low but statistically significant explanatory levels turn vital.

This study converges in the construction of a mechanistic, functional and dynamic model that describes plant growth, identifying key variables that may play important roles in determining canopy size simulating growth under different ambient situations.

This study continues by addressing root hydraulic conductance, vigor confer by grafting with a common scion, and further QTL mapping.

# Direct impact of high temperatures on grapevine berry development: a merge transcriptomic, proteomic and metabolomic survey

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Among various environmental factors, temperature is a major regulator affecting plant growth, development and fruit composition. The grapevine reproductive development and the berry organoleptic properties are both highly influenced by temperature. The molecular mechanisms involved in grapevine berries tolerance to high temperatures are poorly understood. To better characterize the sensitivity of berries to the microclimate, high temperature conditions (+ 8°C) were locally applied to clusters from Cabernet Sauvignon fruiting cuttings at three different developmental stages. Samples were collected 1, 7 and 14 days after treatment and subjected to transcriptomic (NimbleGen arrays), proteomic (Label Free LC-MS/MS) and metabolic analyses.

Results showed dramatic and specific physiological changes in developing grape berries exposed to heat stress (HS), according to the developmental stage and the stress duration. The HS delayed the onset of véraison and strongly impacted anthocyanin contents at maturity. It also significantly affected the primary metabolism with modifications observed in the concentration of amino acids, organic acids as well as with a strong reduction in shikimate and several sugar phosphate metabolites contents. A deep remodelling of both transcriptome and proteome in stressed berries can explain these observations. More than 7000 genes and 2000 non-redundant proteins were found deregulated upon HS. A Genome Ontology category enrichment analysis indicated that the most affected processes belong to stress responses, protein metabolism, primary and secondary metabolisms. Others categories are also well represented: photosynthesis, cell wall, hormone metabolism, RNA, DNA, signalling and transport. Based on these omic data, several putative key players of the HS response were selected and their functional characterization initiated. Our results highlighted the role of *VvGOLS1* (galactinol synthase) and *VvHsfA2* (heat stress factor) in the HS-dependent accumulation of galactinol, putatively acting as a signalling molecule (Pillet et al., 2012). The role of two transcription factors in triggering the HS responses is under investigation, through the combination of complementary approaches (CRES-T, stable grapevine transformation, RNAseq, VIGS).

Taken together, our results highlight the intrinsic capacity of grape berries to perceive heat stress and to build adaptive responses through the mutual action of many key players.

# Climate change conditions (elevated CO2 and temperature) and UV-B alter grape ripening rates and impact berry composition

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Atmospheric carbon dioxide ($CO_2$) and temperature levels are expected to increase in the next decades. In addition, changes in climate as well as changes in stratospheric ozone concentration may affect the exposure the viticultural regions to UV-B. This will most certainly affect berry ripening rates and berry composition at harvest, potentially impacting wine quality. In this work, greenhouse experiments were designed and performed to analyze the combined effects of increase temperature, $CO_2$ and UV-B levels on leaf physiology, berry ripening rates and berry composition (sugars, acids flavonoids) at harvest. Three UV-B doses [0, 5.98 and 9.66 kJ/(m2·d)] and two $CO_2$–day/night temperature regimes (390 µmol/mol $CO_2$–24/14°C, and 700 µmol/mol $CO_2$–28/18°C) were imposed on *Vitis vinifera* cv. Tempranillo fruit-bearing cuttings from fruit set to maturity.

The results show that photosynthetic rates were higher under elevated temperature/high $CO_2$ regime (700 µmol/mol $CO_2$–28/18°C), however high levels of UV-B down regulate carbon fixation rates, although a transient recovery took place at veraison. Photosynthetic and fruit ripening rates were always correlated throughout berry maturation, and the hastening effect of elevated temperature/high $CO_2$ regime was attenuated by high UV-B radiation doses. Regarding berry quality buildup and final (at harvest time) composition, elevated temperature/high $CO_2$ regime decrease the time necessary to reach technological maturity (sugar to acid ratio) but decreased anthocyanin content at harvest; while high UV-B doses slowed down berry ripening (particularly sugar accumulation) and up-regulated flavonol and anthocyanin biosynthesis.

In conclusion, UV-B radiation, which modulates leaf carbon fixation rates, sugar accumulation and flavonoid biosynthesis in berries may partially alleviate the deleterious effects of elevated temperature and high atmospheric $CO_2$ on berry composition at harvest. This study illustrates the complexity of the interactions that exist between stress factors related to ongoing climate modifications, and points out the importance of using combined stress approaches to investigate the impact of predicted future climate conditions on grapevine physiology and grape berry ripening.

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# Phenotypic variability for phenology among wild Vitis genotypes

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Between and within each species of the genus Vitis, there is a great variability for many traits related to the adaptation to biotic and abiotic stresses. If the variability within the species Vitis vinifera is well characterized in respect to the stages of development and phenology (Parker et al., 2013), the one existing between other Vitis species is much less described. In the context of adaptation to climate change, the interest of these Vitis species to create new vine varieties resistant to major diseases should include phenological properties and adaptation to abiotic stresses. The work presented here summarizes the main results obtained for the main phenological stages within a hundred wild Vitis representing 20 different species. The different genotypes were investigated as scions and as rootstocks in two different projects. The phenological stages, bud-burst, flowering, veraison, were recorded for 3 consecutive years. A difference of more than 60 days was noted for bud-burst and ripening stages for the varieties studied as scions, while not exceeding 15 days when varieties were used as rootstock. The results are very well correlated from one year to another, demonstrating the strong genetic control of these phenological parameters. Phenological characteristics of the rootstock are not transmitted to graft by the rootstock. Nevertheless the roostock affects the phenology of the scion. The genetic variability for phenological stages of the scions within the genus Vitis could be useful for breeding purpose in order to combine disease resistance and adaptation to climate change. The "rootstock" effect could contribute, with other viticultural practices, to the adaptation to climate change when the change of scion variety is problematic.

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# How climate change may affect grapevine susceptibility to Botrytis Bunch Rot?

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Botrytis Bunch Rot (BBR) is a major fungal disease of grapevine worldwide due to the necrotrophic fungus *Botrytis cinerea*. The pathogen presents a complex life cycle in the vineyard, with a great genetic and phenotypic variability and various infection pathways, all highly dependent on meteorological conditions. *B. cinerea* can reduce both yield and wine quality, especially a loss of sensory quality perceptible from a severity threshold of 5% rotted berries at harvest. Thus, in the context of climate change and possible grower adaptation by changing of cutivar, it is necessary to better know the susceptibility of the main grapevine varieties to this disease and what new cultural strategies may be adopted. Grapevine growers are considering possible adjustments in their management to maintain the wine typical quality features despite global warming, such as increasing the bunch number per vine, interfering with grapevine phenology and/or introducing new cultivars. However, what about the grapevine diseases according to the cultivar(s) introduced? That is why a study was carried out, under two contrasting weather conditions, to evaluate and compare the susceptibility of different cultivars to Botrytis Bunch Rot (BBR). In the Bordeaux region, several studies confirm that the climate scenario for the next 50 years will be characterized by lower rainfall and higher temperatures. These conditions may be considered are similar to the current climatic conditions observed in other grapevine areas in the world, such as the Central Valley of Chile, which may be considered as close to a future climatic scenario for the Bordeaux region. Then this study allowed us to compare 13 cultivars in terms of susceptibility to BBR under two different climatic conditions: i) near Bordeaux in France and ii) in the Talca region (Central Valley) in Chile. The study was repeated for three and two consecutive seasons near Bordeaux and Talca, respectively. The BBR development in untreated vines by anti-Botrytis fungicides was evaluated at harvest. The results showed, in general, a similar susceptibility classification of the cultivars in both locations. However, the cultivars develop less BBR in the Talca region compared to Bordeaux, due mostly to the differences in climatic conditions. Thus, in the future, adaptation strategies may be orientated by adapting the cultivar choice according to the disease susceptibility, taking into account that the BBR risk might tend to decrease in the Bordeaux area according to the climate change context.

# Polyphenomics based on UPLC-QqQ-MS for deciphering the genetic bases of grapevine response to drought

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Phenolic compounds represent a large family of grape secondary metabolites, essential for the quality of grape and wine and playing a major role in plant defense against biotic and abiotic stress. Phenolic composition is genetically driven but also greatly affected by environmental factors and in particular by drought. A major challenge for selection of grapevine cultivars adapted to climate change and with high potential for winemaking is to dissect the complex plant metabolic response involved in adaptation mechanisms.

A targeted metabolomics approach based on UPLC-QqQ-MS analysis in the MRM mode (Lambert et al., 2015) has been developed for high throughput profiling of the phenolic composition of grape skins. This method enables rapid, selective, and sensitive quantification of 96 phenolic compounds (anthocyanins, phenolic acids, stilbenoids, flavones, flavanones, flavan-3-ol monomers and oligomers…), and of the constitutive units of proanthocyanidins (i.e. flavan-3-ol oligomers and polymers, also called condensed tannin), giving access to detailed polyphenol composition.

It has been applied on the skins of mature berries from a core-collection of 279 V. vinifera cultivars grown with or without watering to assess the genetic variation for polyphenol composition as a response to differential water availability, in the frame of the EU project Innovine. Chemometrics analysis of the phenolic composition data has shed light on the genetic diversity of vine metabolic response to drought.

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# Effect of Abscisic Acid (ABA) on photosynthesis, carbon export from leaves and sugar import in berries of *Vitis vinifera* L. cv. Carménère

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Abscisic acid (ABA) is a plant hormone known to play a key role in plant adaptation to drought, increasing its concentration upon water stress conditions. This is of particular interest in the context of climate change, where water supply is thought to decline worldwide (Chaves et al., 2010). In leaves, ABA is considered a major signal for stomatal closure, declining photosynthesis and potential yields. In grapevines, at the grape berry level, a shift in phloem unloading from symplastic to the apoplastic pathway has been observed at veraison, preceded by an increase in ABA concentration (Zhang et al., 2006). Still, the role of ABA in the modulation of the source to sink ratio under stress conditions, remains unclear.

Two independent assays were established in a commercial vineyard, located in Maipo Valley, Central Chile. Solutions with ABA were sprayed on clusters (A1): T0: 0 µL L-1 and T1: 85 µL L-1, and leaves (A2): T0: 0 µL L-1 and T1: 170 µL L-1, in order to determine its effect on photosynthesis, sugar content in berries and carbon stock in leaves of Vitis vinifera L. cv. Carmenérè.
S-(cis)-ABA extraction and determination was perfomed by and indirect competitive ELISA analysis. Stomatal conductance, carbon assimilation and transpiration rates were measured simultaneously using a portable photosynthesis system CIRAS-2. Physical and chemical variables in berries were assessed, such as weight (g), volume (mL), soluble solids (°Brix) total acidity (g tartaric acid L-1) and pH. Carbon stock in leaves and sugar content in berries were determined using HPLC. The potential rate of carbon export along the days was calculated, as described by Pastenes et al. (2014).

When applied on clusters, ABA concentration was higher than control along the season. Also, a transient hastening of the ripening process occurred, observed as a rise in sugar concentration, lower acidity and higher pH in berries while, in leaves, an increase in carbon assimilation was observed 1 day after veraison (DAV), in the west side of the canopy. ABA applied to leaves, on the other hand, enhanced its concentration only at 9 to 11 DAV but its effects in leaves were maintained along the whole season, decreasing stomatal conductance, transpiration and carbon assimilation rates, in both sides of the canopy. Foliar concentration of soluble sugars and starch was lower in applied leaves, transiently delaying sugar influx into berries. Nevertheless, despite the evident decline in photosynthesis, berries were capable of reaching the same sugar concentration at 19 DAV compared to control plants.

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# Genes involved in the short and long term responses to water deficit in roots of different grapevine rootstocks

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According to the simulations of climatologists (IPCC, 2013), precipitation regime should be affected by climate change with more variations among seasons and regions. Drought severity should increase especially in the Mediterranean zones. Considering that the scarcity of water will increase in the future, irrigation cannot be considered as a sustainable way to adapt vineyards to drought. Plant material, especially rootstocks, represents a major and low-cost option for adaptation. Although grapevine is considered as a drought tolerant species, there is a large variability among varieties and rootstocks. The physiological mechanisms underlying this variability and their genetic architecture are not well identified. Improving our knowledge about the short and long term responses to water deficit in roots of different rootstocks is a necessity to develop new breeding procedures and select more adapted rootstocks. This work summarizes several studies performed on commercial hybrids or interspecific progeny, all studied as rootstocks, facing short or long term water deficit. They all aimed at identifying genes differentially expressed in roots between genotypes. Their putative role in controlling genetic variability will be discussed.

The transcript abundance of 20 candidate genes involved in ABA metabolism and signaling pathways, or encoding PIP aquaporins was recorded in roots of seven commercial rootstocks grafted with two *V. vinifera* varieties and facing a short term water deficit. In parallel, full root transcriptome was analyzed after two weeks of water deficit for 110R and Riparia Gloire de Montpellier grafted with Cabernet Sauvignon, Syrah or Grenache, using microarray technics. All experiments were performed on potted vines under semi-controlled conditions. The output of these differential gene expression studies was compared to the results obtained from QTL mapping for transpiration responses to water deficit under the control of rootstocks (Marguerit et al., 2012).

At short term, few genes involved in ABA metabolism and signaling or encoding aquaporins were differentially expressed between rootstocks. Scion genotypes affected root responses. However at more long term, full transcriptome analyses show that other pathways were more discriminant. Genes involved in responses to oxidative stress, membrane metabolism and cell wall biosynthesis were affected by the interaction between drought levels and rootstocks. At that stage, no scion effect was recorded on root transcriptome. Location of these genes in the full genome of *V. vinifera* was investigated and compared to the location of QTLs previously identified. Several of them were indeed located in the confident interval of QTLs for transpiration and water use efficiency. These results strengthen the role of these genes as key components of the genetic determinism of drought responses in rootstocks. Further studies should be undertaken to fully demonstrate their interest as molecular markers for drought tolerance.

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# Changing environmental conditions influence the wine grape metabolism during postharvest withering

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Postharvest withering is used to modify certain grape berry quality traits that contribute to peculiar characteristics of wines. This technique is economically important and extensively used in some Italian viticultural areas to obtain high value and robust wines like Amarone and Recioto. After harvesting, selected bunches are laid on trays in dedicated rooms under natural or partially controlled environmental conditions for a period of 3-4 months. During this time berry sugar concentration increases due to water loss, and metabolism is modified significantly as revealed by a profound transcriptome rearrangement. In warm seasons, the anticipated grape harvesting determines an early start of the postharvest withering. In these cases the high temperature condition inside the withering rooms enhances the berry dehydration rate, and the entire process is shortened.To investigate the effect of different dehydration rates on the grape berry metabolism we compared the behavior of different grape varieties stored under contrasting environmental conditions. Such conditions resulted in a traditional "slow" dehydration process and in another "fast" dehydration process. Transcriptomic and metabolomic analyses revealed significant differences among grapes dehydrated in different environmental conditions. The results evidenced that only grapes dehydrated following the traditional slow process showed molecular and metabolite changes associated to the typical quality traits of the wines produced from withered grapes.

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# Regulation of Respiration, Tissue Oxygen Environment and Moisture Content in Response to Seasonal Cues throughout Grape Bud Dormancy

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Grapevine (Vitis vinifera) bud dormancy is a complex phenomenon, orchestrated by a plethora of internal and external factors, all of which intervene concurrently to regulate dormancy onset, maintenance and release. Respiration and reduction/oxidation (redox) metabolism along with various other metabolic processes are known to be optimally regulated during dormancy in relation to oxidative signalling. However, our current understanding of the crosstalk between hypoxia, respiration and oxidative signalling within the grapevine bud meristem is very limited and based on various gene expression studies that are less precise and hence cannot directly relate to spatial organization, activity or function. Hence this research aims to elucidate the role and regulation of these factors through dormancy onset, maintenance and release in grapevine buds in response to seasonal cues in the Flame seedless variety.

Respiratory $CO_2$ consumption and $O_2$ production rates along with bud burst kinetics and moisture content were measured for grape buds, collected from two different regions, Carnarvon (sub-tropical) and Swan valley (mediterranean) in Western Australia with different climatic conditions, from dormancy onset until release. The $pO_2$ gradient of the buds from outer scales to inner primary meristem complex was also recorded.

Dormancy onset for Carnarvon buds seems to occur prior to the end of January as opposed to Swan valley's in April. However both the regions show a uniformly low days to 50% budburst (~50 days). An unusually low (~0.5) respiratory quotient was observed for the buds prior to dormancy onset. Overall respiration begins to increase towards the end of endo-dormancy along with the resumption of bud hydration. The internal meristematic tissues of the bud were maintained in a hypoxic state (low $pO_2$ value ~5kPa) until prior to bud burst, when overall respiration began to increase along with the resumption bud hydration. Following this, the hypoxic condition of the bud was relieved and the internal partial oxygen pressure of the bud was normalized over the entire bud in relation to atmospheric partial oxygen pressure (21kPa) nearer to bud burst.

The buds from Carnarvon and Swan valley exhibit a very shallow dormancy but there seems to be a difference in the time of dormancy onset and release between the two grape growing regions, probably owing to the climatic variation. There is tight regulation of moisture content, respiration and internal tissue oxygen environment throughout dormancy onset, maintenance and release and is speculated to influence metabolism and bud response to environmental cues.

# Ensuring the sustainability of cool-climate Shiraz 'peppery' style in the context of climate change

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Cool-climate Shiraz is gaining increasing popularity in the past decade for its stylistic savoury and spicy aroma. Black peppery spiciness has been considered as the key identifier of high quality cool climate Shiraz in many Australian cool-climate wine regions. Rotundone, an oxygenated bicyclic sesquiterpene, was firstly identified by Australian researchers as the primary compound responsible for this iconic characteristic. In the past four years, the University of Melbourne partnered with Australian wine industry, and conducted frontier researches on this compound. We investigated the influence of 'terroir' and grapevine physiological responses on the production of rotundone in Shiraz grape and wine with a range of vineyard management factors which can be manipulated to increase its occurrence. We have established models to link historical climate factors with rotundone, and used this model to predict future production. The model allows real-time estimation of rotundone production during growing season and in the final wine by measuring grapevine phenological stages and cumulative heat during grape ripening. This enables adoption of precision irrigation and canopy management strategies for achieving favourable or mitigating adverse impacts of climatic change, with the aim of maximising the rotundone concentration of grape berries. Furthermore, integrated with climate projection models, we are able to predict the production of rotundone in wine in future vintages. This research allows iconic cool climate Shiraz styles to be preserved, and allows modelling of new grape growing regions in a changing climate. This report will introduce the latest progresses on the research of rotundone and associated sesquiterpene compounds and give practical instructions on how to manipulate vineyard rotundone production, which are especially important to maintain the sustainability of cool climate Shiraz style.

# Canogrape: mitigating the effects of climate change on berry composition by canopy management

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Primary and secondary metabolites are major components of grape quality and their balances define wine typicity. Global climate change is modifying vine physiology and especially the biochemical composition of grape berries at harvest, by decoupling the phenolic and aromatic maturity (defined by secondary metabolites) with technical maturity (defined by primary metabolites) (Schultz 2000). These alterations will consequently challenge the sustainability of the wine production. To face these challenges, more knowledge of the regulation mechanisms of metabolite accumulation in grape is needed to promote innovated viticultural practices or new cultivar selection (Keller 2010). One of the rapid and efficient ways to mitigate the climate change effect is to modify vine canopy that modifies the relationship between source and sink (Bobeica et al. 2015; Kliewer and Dokoozlian 2005).

The "**Canogrape**" project aimed to obtain a better understanding of the relationship between primary metabolites as well as polyphenol and aromatic composition in response to canopy manipulation, in order to find trade-off points for synchronizing phenolic and aromatic maturity with technical maturity of grape. More precisely, we will use cv. Cabernet Sauvignon 1) to analyze, in fine, the response of yield and biochemical composition in ripening berries, including sugars, organic acids, amino acids, phenolic compounds (tannins, anthocyanins, flavonols, stilbens) and aromatic compounds (including methoxypyrazines, thiols, and precursors of thiols), with UPLC, GC-MS and LC-MS; 2) to link the modified berry composition with wine quality by microvinifications; 3) define the relative sensitivities to canopy manipulation by using non-linear regression methods; 4) to study the physiological mechanisms underlying the different sensitivities of berry composition to canopy manipulation, by measuring the reprogramming of central enzymes with a high-throughput enzymatic platform and qPCR or RNAseq techniques.

The preliminary results showed that different metabolites had distinct sensitivities to the modulation of leaf-to-fruit ratios, attesting possibilities to reduce one specific metabolite while maintain the other metabolites unaffected.

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# *SESSION 3 : Adaptation to climate change*

## *ORAL*

# Issues to be considered for strategic adaptation to climate evolution

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The issue of climate change in the public is largely focused on rising air temperatures and changes in precipitation patterns, yet the array of climatic regions used for grape production worldwide will cause very different challenges depending on the area under consideration, the varieties under cultivation and the type of production in mind (i.e. table grapes, sparkling wine, still wine a.o.).

**Water and evapotranspiration:** The effects of climate change on the terrestrial water cycle show regional differentiated patterns. Temporal and spatial distribution can vastly differ between regions and can show substantial variations (between and within years). Within the existing production areas, water shortage is probably the most dominant environmental constraint, and even in moderate temperate climates, grapevines often face some degree of drought stress during the growing season. Yet too much moisture during some developmental phases such as maturity may actually pose a greater risk in some areas. From rising temperatures it is mostly assumed that water holding capacity of the atmosphere will increase in the future as a function of the Clausius-Clapeyron law (Clapeyron, 1802) which predicts an increase in the saturation vapour pressure of the atmosphere of 6-7% per degree Celsius warming. As a consequence, a simultaneous increase in potential evapotranspiration (ETpot) is assumed which will alter soil and plant water relations. Simultaneously, rising $CO_2$-concentrations in the air will cause stomatal conductance to decrease, which should reduce transpiration rates, thus may counteract the increase in evaporative demand and improve water use efficiency. Models are needed which include the actions of environmental parameters (including $CO_2$) to predict changes in local water budgets in grape growing areas as a basis for adaptive strategies (soil and canopy management, row direction, irrigation a.s.o.).

**Soils and nutrient supply:** Soil temperature has increased at least at a rate similar to air temperature over the past more than 100 years (Böhme and Böttcher, 2011). A relatively unique time series of soil temperatures down to 12m depth since 1889 reveals that soil temperatures in the upper 1m profile have increased by about 2-3°C between April and August as compared to the beginning of data collection. Higher temperature in combination with an increased propensity yet variable spatial distribution of heavy rainfall events seems to have already increased the risk for the development of rot (*Botrytis cinerea*) in some areas and will most likely continue to do so. Additionally, increasing $CO_2$-concentrations will increase plant growth, if water is available, and thus increase the production of biomass which through more frequent hedging to keep the canopy shape may further increase the release of nitrogen and may also cause a rise in greenhouse gas emission rates, such as $CO_2$ and nitrous oxide. Preventive actions to combat *Botrytis* need to be devised on all organizational levels in vineyards, from plant protection, soil management to canopy and bunch structure modifications.

**Varieties:** For a sustainable production, the ultimate adaptation would be the use of varieties tolerant to the expected changes in climate and also tolerant/resistant to diseases currently existing and/or appearing in the future. Selection of clonal variations within certain classical varieties may contribute to a certain degree to achieve a small percentage of these goals, but will never be capable of having sufficient disease tolerance. Will new genetic tools, such as cis-genetics or even synthetic biology, change this in the future despite current public resistance against "genetic modified organisms"?

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# Modified grape composition under Climate Change conditions requires adaptations in the vineyard

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Major effects of Climate Change are an increase in temperatures, a modification in rainfall patterns and an increase in incoming radiation, in particular UV-Bs. Vines are highly sensitive to climatic conditions. Hence, vine development, grape ripening and grape composition at ripeness are modified by Climate Change. Some of these changes are already visible and will be amplified over the coming decades; other effects, although not yet measurable, can be predicted by modeling. This will induce major modifications in wine quality and typicity worldwide.

Vine phenology is driven by temperatures. A significant advance in phenology (i.e. budburst, flowering and veraison dates) is observed since the early 1980's in most winegrowing regions. The combined effect of advanced phenology and increased temperatures results in warmer conditions during grape ripening. In these conditions, grapes contain more sugar and less organic acids. Composition in secondary metabolites, and in particular aromas and aroma precursors is dramatically changed. Increased drought, because of lower summer rain and/or because of higher reference evapotranspiration ($ET_0$), induces earlier shoot growth cessation, reduced berry size, increased content in skim phenolic compounds, lower malic acid concentrations and modified aroma and aroma precursor profiles. Increased UV-B radiation enhances the accumulation of skin phenolics and modifies aroma and aroma precursor profiles.

Changes in grape composition modify wine quality and typicity. However, these modifications can be limited through adaptations in the vineyard. Major adaptations can be reached though modifications in plant material (grapevine varieties, clones and root-stocks), vineyard management techniques (vine architecture, canopy management, harvest dates, vineyard floor management, timing of harvest, irrigation) or site selection (altitude, aspect, soil water holding capacity).

# Projections of suitable wine growing regions and varieties: adaptation in space or place?

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Winegrapes (*Vitis vinifera* L) are the most valuable horticultural crop in the world with nearly eight million hectares of vineyards in cultivation. Different varieties of winegrapes (e.g., Pinot Noir or Grenache) exhibit an unprecedented amount of phenological and genetic diversity for a cultivated species, which is an important resource to buffer against climate change. Matching phenological strategies of the different winegrape varieties to a particular climate is a fundamental aim for every vineyard manager, especially in the face of significant climatic shifts in many winegrape growing regions. Yet current projections of suitable winegrape growing regions based on future climate scenarios are limited in their utility, as they do not consider the possibility that other varieties better suited to a future climate could be planted within an existing region. For our projections, we built phenological models for the nine most-planted winegrapes globally, which constitutes over 40% of all planted hectares, using a global dataset of budburst, flowering and veraison. These models were then used to characterize the growing range of 1300 globally planted winegrape varieties. Combing these models with climate projection models under RCP 4.5 and 8.5 emission scenarios we examined future distributions of suitable wine growing regions, as well as the turnover of suitable varieties within existing regions. In some regions of the world, predicted climate change will not significantly alter the varieties that are able to grow, while in others there will need to be shifts in the region itself or in the varieties that are currently planted. Some regions will also see a significant increase in the number and diversity of varieties that can be grown. Our results suggest the need to utilize the full range of winegrape diversity available when considering adaptive strategies in response to changing climates.

# How to translate narrative scenarios in landscape dynamics: Application to the introduction of irrigation in vineyards

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In order to secure long-term investment in terroir, to ensure stable and steady vintage quality and to mitigate climate change impacts, more and more vinegrowers consider irrigation as a possible solution. However, the introduction of irrigation in a vineyard area is often hampered by limitations in water resources and competing uses. The impact of introducing vineyard irrigation in a landscape can be minimized by a purposive (and collective) strategy of selection of the parcels to be irrigated. Ex-ante studies of such strategies, require spatially explicit scenario of progression of irrigation in a vineyard following possible alternate strategies while accounting for the driving forces affecting land use, such as socio-economic crises or climate change. Although narrative scenario are largely used in the scientific community working on prospective, their spatialization at fine scale for accounting for future local decisions is still difficult. Two main reasons explain this phenomenon: diachronic dataset at fine spatial and temporal scales are difficult to obtain and there is a lack of innovative frameworks to translate storyboards in fine-resolution landscape models.

We aim at describing a probabilistic model adapted to a polygonal landscape (vectormode) to simulate changes in land cover at fine resolution scale. The model is based on transition matrices between land uses, applied on constrained maps that reflect the spatial heterogeneity of a given trend. The landscape evolution is forced by non-spatial drifts such as climate change or political decisions.

Here, we explore the capacities of the model to simulate plausible scenarios of land use change when irrigation is introduced in a vineyard subjected to climate change. Land uses are categorized in three levels according to the Corine Land Cover nomenclature: artificial surfaces, agricultural areas, forests and semi-natural areas. Sublevels are especially defined for the purpose of the study, as irrigated and non irrigated vineyards. Climate change is defined by an hypothetical increase in number of consecutive years of drought in the area. The model is based on a diachronic dataset covering the period 1960-2014 in a large watershed of about 200 km2. We postulate that introduction of irrigation in this area is mainly driven by two constrained maps: sensitivity of vineyards to drought and cost access to irrigation for each plot. We considered also that vineyards could be abandoned after being exposed to several years of drought. The abandonment of vineyards is spatially driven by a constrained map of vineyards potentials. Finally, the urban expansion on the zone is defined by a constrained map issued from distances to the town centers.

We tested three narrative scenarios: the first one represents the “business as usual”, simply extrapolating the global trends issued from the diachronic dataset, and the last scenarios relate the introduction of irrigation in the area with two different strategies of farmers to maintain their vineyards. For the first strategy, all vineyards are maintained, enclosing the ones subjected to stress. For the second strategy, farmers preserve only the vineyards with the best potentials.

The variation of the water volume of the dam located upstream and the overall potential of the vineyards is analyzed against time for comparison between scenarios. The potential of the model to simulate complex landscape evolutions is discussed.

# Vineyard drought adaptation in the Douro demarcated region

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The climate change scenarios point out to significant variation in the Mediterranean temperature and rain patterns, circumstances of great importance in the vineyards of the Douro Region, northern Portugal, which are already exposed to harsh summer (hot and dry) climate conditions. Those expected variations are likely to cause a decrease on the production and quality of wine. Although some studies are available, regarding the most adapted cultivars of grapevines to adverse conditions, few of them are performed to understand the actual mechanism of adaptation behind the tolerance to drought. Hence, this preliminary study intends to elucidate some of the basic mechanisms of adaptation of different cultivars, grafted onto several rootstocks, to withstand drought. Two different grapevine cultivars traditionally sensitive to heat and water stress in Douro Region, Tinta Barroca and Tinta Roriz (*Syn*. Tempranillo), grafted onto four rootstocks, Rupestris du Lot, 1103 Paulsen, 110 Richter and 196-17 Castel, grown in the Cavadinha vineyard (Symington Family Estates) in the Douro Demarcated Region, where analysed in several leaf anatomical (xylem vessels and tissue measurements) and biochemical (waxes, photosynthetic pigments, soluble sugars, starch and non-structural carbohydrates content, total phenolics, proteins and Thiobarbituric Acid Reactive Substances –TBARS, as an indicator of lipid peroxidation) parameters. Furthermore, anatomical and biochemical analyzes of grape berries were also performed. Overall result, although preliminary appear to show different mechanisms of adaptation to drought, when comparing cultivars. Regarding Tinta Barroca cultivar, the adaptation to drought appears to occur by leaf morpho-anatomical modifications (higher lamina, upper and lower epidermis and cuticle thickness, as well higher waxes content), as well as by osmotic regulation (higher content of non-structural carbohydrates) while, for Tinta Roriz cultivar, biochemical changes (higher content of photosynthetic pigments and lower TBARS, as well lower content of non-structural carbohydrates) suggest a biochemical adaptation. Furthermore, the grape berries maintained the characteristics associated to each cultivar.

# Cooperative winery can be a major actor for adapt viticulture locally?

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Wine-growing areas are agro-systems examples where the production is highly dependent on environmental constraints. Climate change is a major stress added to those that already weigh on viticulture (White et al. 2006).

If climate change is not disputed, it is the vine-grower capacity to take advantage of their environment and agricultural practices that now need to be explored. A corpus of scientific studies emerged in the literature to tackle these issues with divers methodologies (Duchêne et al., 2012; Viguié et al., 2014; Quénol et al., 2014).

The Banyuls-Collioure AOC (controlled designation of origin) in the Pyrénées-Orientales area of France is representative of the southern part of France where most of the wine production is made by small-scale vine-growers who are mainly organized in cooperatives. Meanwhile, questions of adaptation to climate change are becoming increasingly pressing (Van Leeuwen et al., 2013), particularly in the south of France and Mediterranean Basin. **What would be the future of these areas if tomorrow the mountain environment was no longer perceived as a constraint, but rather as a land of refuge to face climate change?**

We will explore this question via a spatially-explicit agent-based model, by focusing on the self-organization strategies implemented by agents to meet the cooperative's quality requirements. We have created a simulation environment, built from geographic information system data, field surveys and economic values related to the Banyuls-Collioure AOC area. This work has two aims considering climate change: 1) to attempt to provide global insight into how a mountainous vine-growing area can react and adapt to new challenges, and 2) to investigate cooperative policies and their implication on the vineyard landscape stability that can be a source of local development.

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# Climate change and adaptation: Alsace and Loire Valley vintners' challenging point of view

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Climate and biology research infer changes in the vine culture and wine characteristics from some climate variables, which they are reasonably sure will evolve. Social sciences are then asked to watch whether the vintners and wine makers are ready to adapt to these changes and how they will or have readily started to proceed. The second question asked to the social sciences regards the mitigation or adaptation situation of the vintners. Adaptation is often considered as a last resort, when the climate change is too strong, can no more be compensated and threatens the stability of the world and its activities. In this case, the pressure on the inhabitants of the planet should be enforced so as to make them change their ways of life, activities and general practices so as to lower their effect on climate change.

The interviews with the French vintners and winemakers of our field study in Alsace and Loire Valley show quite a different image and structure of concerns. Actors notice many changes in their vines and wines, but climate is not the only one change occurring in the world: markets, customers, tastes, techniques change constantly. The question is therefore, which of these multiple changes can reasonably be attributed to climate change? This question is made even more complicated because most of the expected climate change effects converge with recent technical changes, which have been fostered by the vintners themselves and part of the wine and PDO administration.

For vintners, the expected effects of climate change are therefore often most welcome although as the expected result of technical change some of them, like the increase of sugar un the most, seem to have met their target and would need to be controlled and stopped. Yet, the question of the attribution of the effects to one change or another is not as important as the management of the diversity of the wines, which they all foster. This question is even more acute in the Denominations of Origin because of their framing of the quality and its diversity. So if climate change is not such a worry for the vine growers, the diversification of the wines qualities it seems to contribute to has become a major issue.

Vintners do not raise major problems regarding the adaptation to climate change, which is for them a minor change compared with all the changes they are used to face every new year. They experiment new techniques, new wine qualities… sometimes they ask the researchers to provide them with specific vine varieties or vine growing more efficient practices. But, most of all in the PDO, these demands always face the difficulty of fitting with other requirements regarding market, consumer ethics, specific wine aesthetics, environmental issues among others.

Finally, from the actors' point of view, the problematic regarding mitigation or adaptation is somehow senseless, because the world is not and has never been stable. It is on the contrary facing constant changes. So it is absolutely impossible to differentiate between mitigation and adaptation, just as it is impossible or very difficult to differentiate adaptation to climate change and other types of changes.

# Process-based models for analysing grapevine genotype adaptation to climate change: issues and challenges

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Process-based plant models are increasingly used in agricultural research over the last decades, and are undoubtedly interesting tools which allows quantifying plant responses to environmental factors within a mathematical framework. The purpose of theses approaches is to improve (i) understanding of key physiological processes that determine whole-plant behavior and fruit quality, and (ii) characterization of phenotypes plasticity. Environmental factors are often considered as model-driving variables, and plant- or genotype-specific coefficients are used to represent physiological characteristics. As a result, these models can offer significant advantages in assessing and predicting the effects of climate change as compared to purely statistical or rule-based ones based on previously collected data. More recently, process-based models combined to genetic approaches have also been shown to provide a relevant framework for analysing genetic diversity of complex traits and enhancing progress in plant breeding for various environments. Indeed if the models adequately describe the effects of the genetic variability in a few climatic scenarios, they can be extended to a much larger number of scenarios in order to evaluate the comparative advantage of a given allele in different hypothetical environments associated with climate change. Such an approach provides a way of overcoming the uncertainties associated with gene and environment context dependencies that currently impeded the progress of molecular breeding. Models integrating physiological processes and their genetic control will form the first step to design and test in silico plants for future environments.

In grapes, modeling plant abiotic stress tolerance and fruit quality is still a challenging issue. An overview of the present knowledge and main process-based models in literature dealing with this topic will be presented. Models developed for phenology, plant drought response and berry sugar accumulation will be outlined. These models consist of simple responses curves for one trait or are able to simulate more complex physiological processes. Genetic parameters were defined and their variations among genotypes or segregating populations analysed. The potential use of such models to simulate ideotype behavior under future climatic conditions will also be discussed.

# How can grapevine genetics contribute to the adaptation to climate change?

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Climate change is modifying the environmental conditions in all the vineyards across the world. The expected effects on grape and wine production can be positive in some grape growing regions but under warmer or dryer conditions the volume and quality of the wines produced can be impaired. Adaptation to new climatic conditions include changes in the cultivation areas, changes in the vineyard or cellar practices, or use of new rootstock x scion combinations. In this review, we will provide a quick overview of the possible effects of climate change on grapevine physiology and berry quality and we will describe the more important traits and the genetic variability that can be used in the adaptation process. We will also present the modern techniques that can be used by researchers to identify the links between genomic information and behaviors in the field. Finally, we will discuss on the existing opportunities in the present grapevine collections and on the strategies that can be used by breeders to create new varieties.

# New plant phenotyping technologies in a changing climate

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Climate change is altering the environments in which grapevine develops. Determining responses to environmental changes will require an understanding of the environmentally induced variation in the phenotype of individual vines. This issue is even more crucial in scenarios of high environment variability occurring under climate change. In this work, new plant phenotyping technologies and tools are presented to address several key grapevine traits. Hence, new, non-invasive sensing technologies, including computer vision, thermography, spectroscopy, chlorophyll fluorescence and hyperspectral imaging were compared with traditional methods and tools used in viticulture. Computer vision systems were powerful tools to assess the grapevine yield components. Hence, the number of flowers per inflorescence could be estimated using a smartphone app based on computer vision technologies. Plant water status can be assessed using thermal imaging or NIR spectroscopy as non-destructive technologies. Variety discrimination can be performed using hiperespectral imaging under lab conditions and by NIR spectroscopy under field conditions. Grape colour can be appraised in the field using optical and portable chlorophyll fluorescence based sensors. Moreover, several non-invasive sensors can be embedded and mounted on a vehicle or in a robot for field high-throughput plant phenotyping, enabling the assessment of multiple viticultural features simultaneously. New multi-sensor plant phenotyping mobile platforms are proposed for vineyard monitoring for the wine industry.

# How to adapt winemaking practices to modified grape composition under climate change conditions?

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Major expected effects of climate change are an increase in temperature and changes in rainfall patterns and incoming radiation. As a consequence, vine phenology and grape composition at harvest should be dramatically modified. The main consequences on grapes are more sugar and less organic acids but composition in aroma and phenolic composition of wines is also affected. Winemaking practices have therefore to be adapted and the interest of new approaches has to be evaluated.

Reducing ethanol concentration in wines poses a number of technical and scientific challenges. Several technologies have been developed and some of them are already available for winemakers. Their effectiveness as well as their consequences on wine quality are discussed. Looking for specific yeast strains with lower alcohol yield is also of great interest. Several non GMO strains – *S. cerevisiae* or interspecific hybrids of the *Saccharomyces* genus - have yet been developed, using different strategies, and some of them permit to decrease the final ethanol concentration by up to 1%. Yeast protectors could be also added during yeast rehydration, in order to increase resistance to alcohol and the viability of cells at the end of fermentation. The control of wine acidity is also a main objective as high pH is detrimental both from an organoleptic and a technological aspect. Several membranes –based processes now permit to correct wine acidity with a moderate impact on wine quality. A yeast strain combining acidifying capabilities and low ethanol yield has also been developed.

In the context of climate change, adaptation of winemaking practices and implementation of novel techniques are major challenges for winemakers.

# Severe trimming and enhanced competition of laterals as a tool to delay ripening in Tempranillo vineyards under semiarid conditions

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An advancement in grapevine phenological stages, including ripening, is occurring worldwide due to global warming and, in the hottest seasons, already results in a lack of synchrony between sugar and phenolic ripeness and leads to unbalanced wines. In order to cope with this fact, a general effort is being made by researchers and growers aiming at delaying ripening through cultural practices, particularly under warm growing conditions, where these effects are more deleterious. The aim of this work is to evaluate to which extent severe trimming and enhanced competition of laterals can delay ripening in Tempranillo vineyards under semiarid conditions.

The experiment took place during two consecutive seasons in Traibuenas (Navarra, Spain) in a cv. 'Tempranillo' vineyard. Vines are trained to a VSP spur-pruned bilateral cordon. A severe mechanical pruning was performed ca. 3 weeks after fruit-set, in order to reduce leaf-to-fruit ratio, and, in the trimmed plants, three irrigation doses applied until harvest aiming at enhancing lateral growth, hypothesized to compete with ripening. All measurements were performed in six 10-vine replicates per treatment.

Trimming reduced leaf area and yield significantly and, probably due to it, resulted in higher water availability in trimmed plants. All the ripening process was delayed by trimming: mid-veraison was delayed about 5 days, and the delay of sugar accumulation and acids degradation was longer, differences being clearer in malic than in tartaric acid concentration, which proves the potential interest of trimming by itself. The use of increased doses of irrigation compensated the losses in yield caused by trimming. As expected, the highest irrigation doses increased laterals' growth, and implied an additional delay of ripening, indicating the additive effect trimming and increased irrigation. Nevertheless, it is necessary to further analyze the implications the obtained delay has on other aspects of quality, since, in general terms, anthocyanins and phenolics values were lower in trimmed vines but it was not solely due to delayed ripening, as lower values were observed even when data were compared for a given total soluble solids content.

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# Should water supply by irrigation be soon a technique to manage aromatic potential of Colombard in South-Western France Gascony vineyard?

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The aim of this work is to sustain the aromatic typicality of *Vitis vinifera* Colombard cv., taking into account that the aroma expression of this white Gascony wine is its main issue to market access. The Gascony vineyard in the South-western France, undergoes a temperate oceanic climate with regular but heterogeneous rainfalls in summer. It may in the future face hotter temperatures, increase of evapotranspiration and less rainfalls. This experiment used irrigation as a tool to manage the vine water status and finally influence the content of varietal thiols in Colombard wines. The study took place from 2010 to 2014 on an experimental plot of 300 grapevines where irrigation was led by drip system. Two different strategies of deficit irrigation were tested each year during pre and post veraison periods in comparison with a rainfed control. Vine water status was rated by the measure of stem water potential on grapevines during season, by the estimation of soil water content with WaLIS soil water balance model, and by the analysis of $\delta^{13}C$ in sugar at harvest. The grapes were vinificated at pilot scale under reductive standardized conditions to maximize their varietal thiols expression. As results, we observed a strong variability in the summer rainfalls during the studied vintages and it was not possible to compare directly the rainfed and drip irrigation grapevines production. Soil water availability simulated with WaLIS model showed significant correlation with stem water potential measurements on the experimental field. Depending on the rainfalls variability, the irrigation water supply and the grape maturity process, we generated different classes of quality: early or late harvest date associated with modelled soil water status during veraison to harvest period. We showed that, to significantly produce more varietal thiols in Colombard wines, late harvest date combined with a comfortable water availability during veraison to harvest was the best vineyard management choice. These results gave some references in order to conduct a vineyard for white aromatic wines production. The knowledge of soil water availability in viticulture is one the main variable to deal with. It may be easily reachable with modelling tool. Local wine sector should master this fitting device in climate changing context.

# Canopy manipulations to delay ripening: A case study for Pinot noir and Sauvignon blanc

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Grapevine phenology is predicted to advance in response to increasing temperatures due to climate change. As a result we can expect earlier and compressed harvests, and/or increased sugar concentration in the fruit at harvest time. Solutions to mitigate earlier phenology include changing varieties or areas in which grapevines are planted, or using management techniques to delay ripening on existing vineyards (e.g. late pruning, canopy trimming and/or application of plant growth regulators).

The aim of this study was to investigate the effects canopy trimming to alter the source-sink ratio of the grapevine and to determine the effect this has on the timing of veraison and on berry composition. Four cane pruned Sauvignon blanc and Pinot noir vines were trimmed to retain between three and 18 leaves per shoot shortly after fruit set. Veraison was assessed by monitoring the day of the year at which 8° Brix was achieved. Fruit composition soluble solids, titratable acidity and pH and berry weight were measured regularly from veraison to harvest. Leaf area and yield were quantified at harvest.

Trimming shortly after fruit set delayed the date of veraison for both varieties by up to a week. Lower rates of soluble solids accumulation reflected reduced leaf number. The rate of accumulation at any leaf area: fruit weight ratio was similar for both varieties. As a consequence the date at which a target soluble solids was achieved was later at lower trim heights and in extreme treatments the soluble solids did not obtain a commercial concentration by the end of the season.

Manipulating the source-sink ratio of grapevines by trimming, to reduce photosynthetic source for the vine may be used to delay the onset of, and slow the rate of soluble solids accumulation. This technique to slow the ripening phase may counter some of the advances in fruit development seen as a result of climate change. The results also suggest that leaf area: fruit weight ratio affects the date of veraison and rate of soluble solids accumulation in a similar way for different grapevine varieties.

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# *SESSION 3 : Adaptation to climate change*

## *POSTER*

# A probabilistic model for sustainable wine growing

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Objectively evaluating the quality of a vineyard in the context of climate change is not always simple. Bayesian networks are widely used for knowledge representation and reasoning under uncertainty in natural resource management. There is a rising interest for this methodology as tools for ecological and agronomic modelling. We designed a probabilistic model that takes into account the parameters defining the status of a vineyard with their associated interactions. No such model has been developed before. It includes an inference engine and software. Data were collected from vine-growing experts. The model includes a database with more than 660 grape varieties. For climate, our model uses a classification method (Tonietto and Carbonneau, 2004) involving multivariate measurements of climate on the basis of three indices: heliothermal index (HI), cool night index (CI), and dryness index (DI). Our model should ease assessments of the likely impact of the choices and decisions of vine growers on the quality of new vineyards to be planted. Thanks to this mathematical model, any kind of simulation of climate change based on the international indexes can be performed. Some examples will be presented. Same thing concerns a primary evaluation of models of sustainable Viticulture. The general frame of the G*i*ESCO charter of sustainable Vitiviniculture is reminded on that occasion.

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# Development of a model of flooding response in grapevine – Preliminary results

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According to WMO, the world experienced unprecedented high-impact climate extremes during the 2001-2010 decade. Furthermore, in 2013 IPCC reported that nearly 94% of countries had their warmest decade in 2001-2010, with droughts occurring in all parts of the world and floods being the most frequent extreme event over the course of the decade. Under this climate change scenario, traditional wine-growing regions, where terroir expression has been optimized through millenary experience, will likely face more frequent and intense extreme weather events.
In particular, root exposure to prolonged hypoxic conditions produced by temporary flooding of the soil, caused by high rainfall, faulty irrigation, unleveled land, poor drainage or heavy soil texture, induces multiple plant physiological dysfunctions leading to a decline in vine growth, yield and enological results from the qualitative point of view. Studies carried out on model species revealed that oxygen deficiency in the soil (hypoxia or anoxia) due to waterlogging conditions leads to anaerobic processes in the rhizosphere (i.e. microbial respiration), a drop of citoplasmatic pH, the accumulation of toxic metabolites in both the root and the rhizosphere, the synthesis of stress hormones (i.e. abscisic acid and ethylene) and the production of reactive oxygen species (ROS). To date information available on the physiological responses to flooding in grapevine is still lacking due the relative low frequency of flooding events occurrence until recent decades.

With the aim of characterizing the effects of single stresses (flooding, drought and heat waves) and of their combinations on grape physiology, the present work has focused on drawing a first physiological model of grapevine responses to flooding conditions during the dormancy period, as the most susceptible one to high frequency precipitations events.
Vines of Vitis vinifera cv. Sauvignon blanc grafted on K5BB rootstock were grown in 5L pots under hydroponic conditions (modified Hoagland) and arranged in two experimental conditions: control (plants maintained in a constantly oxygenated solution) and hypoxia (plants maintained in a solution without oxygenation and isolated from air). During an experimental period of 8 days, measurements of dissolved O2 concentration (mg/L) and pH were conducted and apical roots were sampled every two days after stress imposition. On the sampled material, molecular markers generally involved in response to hypoxic conditions were analyzed by Real-time RT-qPCR, including i.e. alcohol dehydrogenase (ADH), pyruvate dehydrogenase complex (PDC), ACC synthase (ACS), ACC oxidase (ACO), Sucrose synthase (SuSy). The dataset obtained has been utilized for the development of a preliminary model of the responses dynamics in grapevine roots (K5BB) to hypoxia.

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# VitAdapt: an experimental program to study the adaptation of a large range of *Vitis vinifera* varieties for Bordeaux vineyards

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Introduction – In order to address global warming and its consequences, it seems essential to adapt viticultural practices in vineyards. Given this context, we develop part of our research on the aspect of plant material. For this, we have chosen to study the long term behaviour and adaptation to climate of a wide range of grape varieties. The VitAdapt project was initiated in 2009 to study the response of 52 varieties to climate changes in Bordeaux. The objectives are multiple: to study the behaviour of Bordeaux varieties in a changing climate, to explore the quality and adaptation potential to warmer conditions of potential candidates for introduction in Bordeaux, to develop a large database of phenotyping for these varieties, and finally to establish a chronology of precocity for many varieties and characterize phenotypic variability for a large number of *V. vinifera* cultivars (comparison of different genotypes in the same environment).

Materials and methods – The VitAdapt plot consists of 21 white grape varieties and 31 red grape varieties. All varieties (one clone per variety) were grafted onto a single rootstock. Fifty vines per variety were planted, with 5 replicates of 10 vines, planted randomly in 5 blocks. Measurements focus on phenology (budding, flowering and veraison) and grape composition throughout the ripening period. From mid-veraison to "ripe" grapes, many parameters are monitored weekly: the weight of 100 berries, sugars and °Brix, total acidity, malate and tartrate, Yeast Available Nitrogen, potassium and pH. We also conducted measurements to assess the vigour and others agronomic parameters: pruning weight, mineral status, yield components. The effect of water status on berries is obtained through measurements of $\delta^{13}C$ on grape must at harvest. The sensitivity of the varieties to pests and diseases is also investigated. Since 2015 microvinifications have been initiated on some varieties of the VitAdapt plot.

Results and discussions – Phenology is assessed when 50% of the organs reach a given stage (bud break, flowering, veraison). The varieties are classified according to their precocity. Major differences in precocity were recorded among varieties, with mid-bud break extending over 30 days on average between 2012 and 2015, with mid-bloom extending over 20 days on average. For veraison, we measured the colour change in red varieties, and the change in texture or softening in white grapes. A large variability in the timing of mid-veraison was also observed, extending over 40 days on average. The varieties could also be ranked according to different parameters of ripening, like the day they reach a given sugar level. Varieties are grouped according to the parameters of ripe berries by Principal Component Analysis.

Conclusions – The plot was planted in 2009 and phenotyping started in 2012. Data have been accumulated for four vintages. This will allow us to start multi-year analysis in order to study the impact of climate variability. A better understanding of how these varieties behave will help growers to choose the varieties according to current and future climatic conditions.

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# Climate change and vineyard irrigation: a decision support tool for wine growers.

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Vineyard adaptation to climate change is one of the biggest challenges for viticulture. Wine quality is closely linked to the concept of "terroir" that suggests matching agro-climatic conditions with growing practices. Logically the increasing temperature and the change in rainfall pattern, expected in the next decades, should bring changes in wine-making practices. Mechanistic modelling enables to better assess the impact of climate change on wine production and ultimately to promote alternative solutions. As an example, the ITK Company carries out a study on the effect of climate change on water deficit of representative vineyards located in Costières (Gard) and Pessac (Gironde).

This study is based on simulations carried out with iTK Vigne software developed within a collaborative project involving INRA, CIRAD, IRSTEA, Languedoc wine-growers' cooperatives, the chamber of agriculture and the climate association of Hérault. The study investigates the vineyard water deficit over a 150 years period and the impact of these changes on irrigation management. The effect of cover crop on water deficit is also assessed in Pessac as it represents a common practice in the region. Finally, the evolution of the cool night index (CNI) is investigated the month preceding vine-harvest, as it is related to the aromatic potential of wine and may evolve in the next decades.

The retrospective study first shows that the management mode prescribed by the specifications of "Costières de Nimes" and "Pessac-Léognan" appellations well matched for wine production without irrigation over the beginning of the past half century. However, climate shift then led to an increasing water deficit justifying the use of precision irrigation. Prospective results in Costières indeed show that production objectives should require doubling water input until 2100. Prospective results located in Pessac show a similar trend, however according to the more clement climate point out overall two times less water requirement. Results also underline higher water consumption with cover crop compared to bare soil, which is more pronounced under the more pessimist climate scenario. However, this effect remains negligible on water deficit. This underlines the need to consider other strategies, instead of cover crop management, for saving water the next century. In parallel, the expected earliest vine-harvest date (from 2 weeks up to 1 month) combined with the increasing temperature, should significantly alter the CNI in both regions (up to 6°C). This can be very problematic for wine quality and difficult to counter except by using late varieties.

These theoretical results already show that iTK Vigne is a relevant tool to quantify the effect of climate change on potential wine quality and its interaction with vineyard's management according to different climate scenarios. In this domain, mechanistic models have decisive advantages compared to physical measurement they deliver a continuous follow up of base water potential. It can be used both retrospectively on past field experiments and prospectively using future climate scenarios.

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# Impact of post-veraison trimming on yield components and ripening in two different environments in cv. Sangiovese

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Climate changes, in recent decades, have resulted in an increase of temperature, also reducing the ripening period of many grape berries varieties. These conditions, associated to other contributing factors, such as the general improvement of agricultural techniques, have caused in many viticultural areas too fast accumulation of berry sugars during ripening with excessive alchool level in wine. In red grapes these conditions are associated to unbalanced accumulation of phenolic substances during ripening and recent researches have suggested that the source limitation during ripening through the application of trimming, defoliation or anti-transpirant products around veraison is able to reduce sugar accumulation (Filippetti et al., 2015). of the canopy around veraison may help to reduce sugar accumulation

To better understand how the leaf removal after veraison may modify yield components and berries composition, we here report the results of two independent experiments conducted in two different areas for Sangiovese, the most widely cultivated red grape in Italy.

The first study was conducted from 2009 to 2011 in a low-vigor hillside vineyard with no irrigation, while the second was conducted from 2012 to 2014 on a high-vigor and well-watered lowland vineyard. In both the experiments, vines were drastically trimmed (50% of leaves removed) at the end of veraison (berry sugar concentration around 15–17 °Brix) and the effects on sugar accumulation, yield and vegetative parameters were registered in comparison to untrimmed vines. In parallel, anthocyanins and seed tannins deriving from berries of trimmed and untrimmed vines were analyzed for total concentration (hillside) or for their extractable portion using a wine-like solution (lowland). In high vigor vineyard the trimming at the end of veraison was able to reduce the concentration of sugar in comparison to control without inducing substantial changes in yield components and in the concentration and composition of extractable anthocyanins and seed tannins. In low vigor vineyard similar results were obtained in 2009 and 2010, when grapes of trimmed vines had lower sugar concentration compared to control, with no differences on anthocyanins and seed tannin concentration. Unlike this in 2011, leaf area limitation was insufficient to reduce sugar accumulation, because yield constraints were observed and the leaf area to yield ratio was maintained within the optimal range. On this base the reiteration of strong post-veraison trimming should be carefully evaluated according environmental and vine status as in low-vigor area this technique may showed a consequent compensatory mechanisms inducing a reduction of the yield probably following an excessive depletion of carbohydrate reserves.

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# Grape biodiversity of the vine is a resource to challenge the climate change: a case of study in Sardinia

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Sardinia is the second largest island in the Mediterranean and is characterized both by a large population of wild vines and by an ancient history of wine production, whose oldest traces date back to the Bronze Age (1500 BC.). The high number of individuals of *Vitis vinifera* ssp sylvestris and ancient history gave the result of a large number of autochthonous grape varieties, still present particularly in ancient vineyards.

A high percentage (about the 50%) of the Sardinian grape production is linked to 2 varieties: Cannonau (Grenache) and Vermentino grapes, which are usually harvested, respectively, between the last week of September and first of October and the first week of September. The hypothetical rise in average temperatures could result in changes in phenology and wine characteristics of these 2 varieties. For instance, the influence on Cannonau wines could cause a higher alcohol content but in the same time a lower content in anthocyanins and polyphenols. In the case of Vermentino the increase of temperature could determine wines more alcoholic and a reduction of hints.

With the aim of avoiding the problem of unbalanced wines, the phenology, the production and the quality of grapes and wines from a group of late ripening native varieties have been studied in a three year trial. The study has identified varieties able to produce both wine with similar characteristics (than those made from Cannonau and Vermentino) and new kinds of wine with original organoleptic features.

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# A second spur pruning to delay the cycle of the vine up to two or three months

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The aim of this work was to evaluate a second spur pruning as a tool to substantially delay vine cycle and ripening of the grapes and escape the negative effects of high temperatures.

During the last few years, there is an earlier stage of development in vine phenology (Jones et al., 2005; Duchene and Schneider, 2005). As a result of that, berry ripening is taking place during the warmer period (Webb et al., 2007, 2008).

In warm climatic conditions, the sugar concentrations of red varieties reach more than sufficient levels for obtaining high quality wines, but this is often not the case with colour. This relative stability of sugars compared to the sensivity of anthocyanins to temperature is due to different temperature ranges for optimal activity of the enzymes producing sugars (18 to 33 ºC) and pigments (17 to 26 ºC) (Iland and Gago, 2002; Sadras et al., 2007). This same phenomenon occurs in white varieties, resulting in white wines with high alcohol content and low aromatic content and acidity. Especially, several studies indicate that the trend towards high temperatures during berry development, has a negative effect on berry composition and wine quality (Lacey et. al, 1991;. Mori et. al, 2007; de Orduña, 2010; Keller, 2010; Sadras y Moran, 2012).

There are several viticultural strategies to mitigate this effect trying to delay ripening: reduced leaf area (Stoll et al., 2009, Intrieri y Filippetti, 2009; Martínez de Toda et al., 2014), late and minimal pruning (Martínez de Toda et al., 2015), increasing yield (Kliewer y Dokoozlian, 2005), increasing irrigation (Cooley et al,, 2005), etc., but the achieved delay generally not goes far beyond 15 or 20 days.

In this work, we propose an alternative strategy to delay the vine cycle and, therefore, ripening much longer, even up to two or three months, which can be very interesting in extremely hot conditions, in which the harvest normally takes place in August.

The experiences were developed during 2015 in experimental vineyards of the University of La Rioja, inside Rioja appelation, North of Spain. Several treatments were applied, at five different dates from before flowering to after fruit set, consisting of performing a second pruning on the new shoots developed in the year, leaving two buds spurs and looking for these buds sprouting. Besides getting a good fertility of buds, formed and developed in the same year 2015, the results show a delay in the vine cycle and, therefore, in the grape ripening of up to two or three months, depending on the date of the second pruning.

# High-resolution thermal imagery to estimate water status variability within a vineyard

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Precision viticulture has focused to date mainly on the analysis of the variability of vegetative growth within a vineyard. This approach has been shown to have significant limitations, since it only considers – direct or indirectly – part of the factors determining vineyard yield and harvest quality. This limitation can be particularly true in arid and semi-arid regions, where water availability is known to be crucial for both yield and quality. With this regard, remotely acquired thermal imaging can be a useful tool to estimate within field variability in water status, since it allows determining canopy temperature, which is related to transpiration and, as a consequence, to plant water status. Thermal indices were developed in the 1960s using IR thermometers, and their use as research tools increased when thermal cameras were developed. However, it is now, when thermal camera resolution has increased, and their weight and price decreased, when their implementation in agricultural and viticultural systems can be fully developed, linked to the increased availability of unmanned aerial vehicles (UAVs) that can carry these kind of sensors. The aim of this work was to evaluate to which extent high-resolution thermal imaging allows evaluating the existing variability in water status within a vineyard. There is some preliminary research in this issue, but the novelty and significance of our approach is that very high resolution imaging was used at a commercially relevant acreage (7.5 ha), and that our study measured the natural variability in water status existing within the field, and therefore mirrors the real conditions where vines are grown.

Data acquisition took place at mid-veraison (late July) in a cv. 'Tempranillo' vineyard located in Traibuenas, Navarra, Spain. An 8-rotor UAV, designed and built within the CNR (Italy), was used for image acquisition. This UAV has a maximum 3 kg payload, and has been optimized to carry sensors aimed to objectively characterize within fields variability. During the flight campaign, the UAV was equipped with two sensors: a multispectral Tetracam Snap camera, and a thermal Flir TAU II 324 camera. Flight altitude was fixed at 70 m, giving 4 and 9 cm pixel-sizes for the multispectral and for the thermal images, respectively. The UAV was equipped with a high resolution GPS, that allowed following a pre-established flight itinerary and geolocalization. Images were orthorectified and mosaicked. The information obtained from the thermal images was then used to calculate the crop water stress index (CWSI) using dry and wet temperatures measured in field on leaves that had been sprayed with, respectively, petroleum jelly and water.

Images were acquired in a clear-sky day around noon and, at the same time, stem water potential ($\Psi s$) and stomatal conductivity ($g_s$) were measured at 13 points distributed all across the vineyard. At each sampling point, four well exposed leaves were sampled to determine $\Psi s$ and $g_s$. The comparison of CSWI values with $\Psi s$ and $g_s$ allowed to observe that thermal images were suitable to determine plant water status, as it was very significantly correlated to both ($R^2 > 0.65$, $P < 0.01$). The obtained information also allowed detecting which parts of the vineyard performed similarly from a hydric point of view, validated with $\delta^{13}C$ values obtained at harvest.

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# Can we help these berries in the desert? An approach to prevent over-exposure of berries to radiation and high temperatures

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Ongoing expansion of viticulture from traditional temperate regions into arid regions poses climatic challenges such as high solar radiation, high temperatures, and low water availability, all known to be detrimental to berry quality. These challenges are magnified further in view of climate change and global warming. Practical techniques that address this challenge to control the effect of elevated radiation and temperatures on fruit quality are still lacking. An agro-technique that can potentially improve the berry microclimate is comprised of photo-selective shading nets installed directly around the clusters, maintaining the canopy above exposed. While shading nets have been used extensively in other fruit crops, their use in wine grapes to reduce radiation is limited. Our aim was to study the effect of shading nets application on the micrometeorological conditions surrounding berry clusters, subsequent berry quality and test their practical implementation in commercial settings.

Our research was conducted at a commercial vineyard in the Negev desert, Israel (30.6080° N, 34.8030° E; 800 a.m.s.l). Cabernet Sauvignon vines were orientated in a north-north-east to south-south-west direction, with rows angled 30° to the east. Application of shading nets was performed immediately prior to véraison, parallel to the removal of all basal leaves covering the cluster zone on both sides of the canopy. The following treatments were applied: fully exposed clusters, shading net with 30% radiation block, shading net with 60% radiation block, red shading net with 30% radiation block and blue shading net with 30% shading block.

Air temperature, relative humidity, incoming shortwave radiation, and wind speed and direction were measured continuously from veraison to harvest in the vineyard and in the vicinity of the clusters. Diurnal and night-time berry surface temperature was measured in clusters located on both sides of the vine row (east and west) and from all exposed directions (north, south and east or west). Fruit size, weight, and maturity indices were measured for each treatment every week throughout the growing season to monitor berry development.

Relative humidity and air temperature in the vicinity of the clusters was not affected by the presence of the shading nets, implying that this technique of shading application is not expected to increase berry rot. The diurnal pattern of berry surface temperature was modified by the presence of the shading nets with increased temperature homogeneity correlated to decreased radiation transmittance. Differences in temperature and seasonal thermal accumulation were found between east and west facing clusters. Color and density properties of the shading nets affected the radiation transmittance and intensity, with significant effect to the maximum berry temperature and the thermal dynamics of berry warming and cooling.

These results indicate that application of shading nets through the technique we implemented can mitigate microclimatic challenges in arid vineyards. Further analysis will indicate the effect of the shading nets on the accumulation of berry secondary metabolites.

# *SESSION 4 : Perception and adaptability of climate change by the actors*

## *ORAL*

# Does alternative choice experiment formats matter to elicit preferences and willingness to pay?

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Since its introduction conjoint analysis (CA) has become one of the most popular research tools to elicit consumer's preferences and willingness to pay (WTP). Three of the widely-used CA formats are choice-based conjoint analysis (CBCA), ranking conjoint analysis (RCA) and best-worst scaling (BWS). This presentation makes a comparison, in a non-hypothetical setting, of results obtained from alternative conjoint formats in terms of estimated partworths, willingness to pay, participants' response consistency, and external validity of the estimated partworths.

In the first case study, the choice-based conjoint analysis and the ranking conjoint analysis (recoded as a choice-based conjoint analysis) are compared using small and large choice sets. Results suggest that in a small choice set setting, participants' preferences and willingness to pay are similar across the two conjoint analysis formats. However, in large choice sets, a divergence between the two conjoint analysis formats emerges.

In the second case study, we compare the results from non-hypothetical choice experiment (NHCE), non-hypothetical ranking conjoint analysis (NHRCA) and non-hypothetical best worst scaling (NHBWS). In this case, results suggest that, independently of whether the partworths are estimated considering only the option ranked first or the full ranking information, the three CA formats provide similar results in terms of sign and significance of the estimated partworths as well as the estimated WTP values. However, the results show that NHBWS outperforms NHCE and NHRCA in terms of external validity, especially, when the full ranking information is included in the estimation.

# Lessons from a foresight exercise on the French wine industry under climate change

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Climate Change (CC) has given a renewed interest on Foresight studies, exploring at long term the contrasted futures of socio-economic systems. IPCC used this methodology at the global level in order to define the socio-economic conditions of different Greenhouse Gas emissions scenarios (IPCC, 2010). Foresight Studies are now more and more tested at sectorial, value chains or geographical scales, in order to help policy makers or economic actors to define their strategy of adaptation to CC, which impacts could be radically different according to each sector, chain or region (Cairns et al. 2013; Viguier et al. 2014). This exercise was conducted during the multidisciplinary LACCAVE project, by a working group which aimed at exploring scenarios for the adaptation of the French wine industry to CC in 2050 (Ollat, Touzard, 2014). The group, decided to follow a new approach. After the co-construction of a common representation of the French wine industry, the group selected 4 pre-defined adaptive scenarios by crossing the three main dimensions of adaptation: technological innovation, spatial strategy, institutional changes.
A first "conservative scenario" integrates only incremental changes, allowing to assess the impacts of passive adaptation; The "innovation for staying" scenario focuses on changes in agricultural and oenological practices, trying to maintain existing vineyards at the same place; a "migration scenario" takes into account the possibility for vineyards to move spatially according to climatic conditions; and a "zero-regulation" scenario tests what happens when "anything is possible anywhere".
We collected information from three different "knowledge bases" on the relevant processes and assumptions which can be involved in the realization of these 4 pre-scenarios: i) the outputs from previous foresight studies on the wine industry, ii) the consultation of all the researchers working in the LACCAVE project, and iii) a face to face survey of 42 actors of the wine industry in Languedoc, Bordeaux and Champagne (wine producers, merchants, policy makers…). This information was analyzed and combined by the foresight group, leading to define different clusters of assumptions and narratives, that could be related to the trajectory of each "pre-scenario". This methodology thus focused more on the trajectories that lead to the 4 pre-scenarios (and the dynamic conditions of these trajectories) than on the description of the final scenarios.
This communication presents the foresight methodology carried out by the group, the main results of this two-year work and the lessons that this exercise can provide to both the scientific community of "foresight studies" and the research on adaptation to climate change, specifically in the wine industry.

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# Climate Change Adaptation Requires Integrated, Transdisciplinary Research Across the Value Chain: a Case Study of the Ontario Grapevine and Wine Research Network

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A developing scientific consensus is that current and predicted impacts from climate change may represent humanity's greatest existential threat, yet adaptation responses to date have been very inadequate. Agricultural systems are particularly vulnerable to an altered climate, with the wine industry often considered the 'canary in the coal mine' for climate change, due to the narrow geographic and climatic range required by many grape varieties. Grape and wine are economically important components of Canada's agri-food sector, with the Ontario wine industry - Canada's largest - generating over $3 billion in economic impact each year. However, current and projected climate conditions threaten the industry. These threats include the unpredictability of extreme weather events such as early freezes, mid-winter thaws and spring frosts which affect the region's ability to produce quality wines. Additionally, increased pest pressure, including from Coccinellidae beetles, and a relatively limited range of established wine styles further reduce the resilience of the industry.

This paper gives an overview of the work of the Ontario Grapevine and Wine Research Network (OGWRN) under its mandate to deliver the research necessary for evidence-based decision-making by the industry, as it seeks to meet the challenges of climate change. The OGWRN consists of a consortium of universities, a college and a private research center from Ontario, with support from the provincial agriculture ministry, industry regulatory bodies, and several partnering vineyards, wineries and greenhouses. The Network draws strategically on many disciplines, including climatology, viticulture, oenology, molecular biology, microbiology and consumer science to achieve its objectives.

Highlights from the OGWRN's work that will be presented include the development of regional climatic models to help identify new regions in northern Ontario suitable for quality winegrape production, and the use of both viticultural and molecular approaches to confer greater winter hardiness to grapevines susceptible to freeze damage. Oenological examples include the optimization of yeast and production practices to allow for the full exploitation of emergent wine styles in Ontario, including sparkling and appassimento wines, and the development of novel techniques to remediate juice/wine containing elevated levels of taint compounds associated with warmer winters and increased weather volatility. We conclude that an integrated response to climate change across the value-chain is needed for the wine industry to successfully adapt, and meet the challenges and realize the opportunities afforded by a changing climate. This requires the incorporation of transdisciplinarity as a core strategic principle of research and planning that support this goal.

# Climate Change and Economic Challenge Strategies for Vinegrowers, Winemakers and Wine Estates

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For wine areas around the world, nature and climate are becoming factors of production whose endowment becomes a stake beyond the traditional economic factors: labor, capital and land. They strongly influence agricultural and environment conditions for production. Because of global warming new production areas are suitable for cultivation of vines, entrants appear embarking on viticulture, preventive relocations are underway as well as land purchases which are anticipated future potential, cultivation practices evolve, ....

The persons in charge of wine estates (winemakers, owners, managers, ...) have to adjust continually to the impacts of climate change, a key and permanent concern today. In the vineyard as in the winery or in cellars adaptation is unceasing. Observations of temporal and spatial variability of climate requires unending monitoring in the vineyard, operations vital and costly in time. Simultaneously a strong spatial variability of climate on tight spaces requires responsiveness of winemakers in the vineyard because of high differences caused by local conditions (topography, soil, subsoil ...) both in the short and medium term. For wineries individual adjustment strategies although still implemented through the centuries have become essential or crucial to the future of the working tool. The wide variety of situations (climatic, geographical, economic, ...) requires new decisions to protect properties from incidents and accidents; the consequences of climate may jeopardize the survival of the wine estates especially the small ones (coverage risks, geographic diversification, ...).

Strategic choices have to be decided at each step of the production from the plantation of a vine (grape variety, vine planting density, ...) to commercialization (bulk, bottle, ...) through the kind of wine to produce (red, pink, dry, sparkling, ...). If necessary a reorganization of the vineyards (orientation of rows, local or regional movements) is a costly process. Moreover collective decisions become indispensable such as water management, detecting diseases or parasites, fight against bad weathers, ... They can be critical for the survival of the vineyard and the perpetuation of wine estates.

Furthermore the heterogeneity of demand becomes a new concern: consumers have expectations and tastes very different from one end to another in the world (colors, varieties, wine types, ...), opportunities, circumstances and consumption occasions are extremely varied: with or without food, at home or not, during social gatherings or moment of relaxation ... What products offer? In addition a new challenge is the preparation of consumers (novices, regulars, fans, connoisseur, wine lovers...) to modifications in the organoleptic characteristics of wines; climate change influences the aromatic balance of wines and consumers have to be initiated to accept them.

The presentation aims to highlight the critical decisions and strategies (technical, economic, managerial, commercial, ...) for individual and collective responsible of the wine estates to ensure the economic and financial profitability, a challenge for the sustainability of their domains, while being attentive to the requirements of customers (individuals, wine shops, restaurants, supermarkets, ...) on domestic and international markets.

# Climate change and sustainability in English wine production

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Situated above the 50°latitude and with average heat summations below 900 (10°C base), the wine regions of the United Kingdom now have a successful, booming industry (average increase in vineyard surface of 11.9% per year) and a very strong market for our products. This presentation will illustrate the challenges facing the English wine industry and how it is working to resolve them.

The English wine industry dates back to the times of the Roman occupation, but commercial wine production ceased in 1920. It was revived in the 1950s, working with interspecific hybrids and Germanic *vinifera* crosses, but around 10 years ago it realised that it could produce world-class sparkling wines using Champagne varieties. We are now undergoing a very successful renewal, producing an outstanding luxury product, for which there is a high demand on the home market, and considerable opportunity for the development of exports and wine tourism. However, with only around 2000 hectares of vineyards, this is a small and rather inexperienced industry, very significantly challenged by our maritime climate.

The English wine industry is striving to get itself organised, maintain the quality of its wine and promote itself effectively in the marketplace. It also needs to gain a high level of technical skill, work with changing climatic conditions, and define the key and unique characteristics of its product. A key contribution to this development has been the WineSkills project. This government-sponsored initiative has up-skilled the industry through regular workshops and masterclasses delivered throughout the wine-producing regions of the UK, focusing on vinegrowing, winemaking and wine business. However, most interesting is the work that has been done comparing and assessing the suitability of 18 sustainability schemes from around the world and producing a list of sustainability guidelines that are very practical and uniquely suitable for the UK. These have been promoted on the WineSkills website (www.wineskills.co.uk ) together with further information to enable wine producers to put the guidelines into action. This project may interest delegates from regions which are developing their own sustainability schemes.

Further research initiatives, for instance on site identification, have been successfully completed, and Plumpton College played a key part in the development of the Lifelong learning project e-VitiClimate. It is now a partner in the Life-ADVICLIM project, and has gathered a year's high-resolution precise data on the effect of weather on a vineyard, including phenological development, vigour, yield and ripeness parameters. We would like to present these preliminary results to the delegates of the *Sustainable grape and wine production in the context of climate change Conference*.

We would also like to promote (either orally or by poster) the 9th International Cool Climate Wine Symposium, which will be held in Brighton on 26—28th May 2016. Supported by a wide variety of speakers with international reputations, this meeting of the world of wine will tackle issues which are highly relevant to climate change, such as emerging vineyard pests and diseases, managing climate-based variability and optimising cool-climate wine styles. For more information, see www.iccws2016.com .

# Sustainable wine production in South Africa within the context of climate variability.

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The South African wine industry has always been faced with challenges regarding climate and soil variability, both with regards to long and short term decision making. Recent studies also included South Africa in alarming statements about expected decrease in suitability of some areas for grapevine growing, without adding local knowledge about current production area variability to the debate. It is also very clear in recent years that water availability will be crucial for wine production in certain areas, and that predictions with regards to rainfall spatial and temporal variability are very difficult to do reliably.

Our goal with this communication is to present an overview of our approaches with regards to climate data analysis, with incorporation of remote sensing and other technologies in order to ensure the best possible basis of information of vineyard establishment and management decision making within the climate variability context. Furthermore we aim to present an overview of the diversity of existing climatic and soil conditions in which viticulture is practiced, to provide a perspective on possible adaptations and expected effects of possible future climate shifts/change.

We also present approaches to relate grapevine functioning (reproductive and vegetative) to climate conditions from a combination of field measurements and remote sensing technology

# Assessing local climate vulnerability and winegrowers' adaptive processes in the context of climate change

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Adaptation to climate change is one of the biggest challenges facing the viticulture sector. Temporally, adaptation strategies and policies have to address impacts in both the short- (e.g. wine quality) and long-term (e.g. varietal suitability), whereas spatially, place-based and context-specific adaptations will be critical. In addressing these challenges, contextual vulnerability assessments have emerged as key elements to inform adaptation, by accounting more explicitly for the local factors and processes defining vulnerability and winegrowers' adaptive responses to changing environmental and socio-economic conditions. In this context, this study assessed local climate vulnerability and winegrowers' adaptive processes in two regulated wine producing areas in the Anjou-Saumur wine growing sub-region (France). For the purpose of the study, qualitative data were collected through semi-structured interviews with thirty winegrowers.

Climate-related exposure and sensitivity were dependent on many contextual factors (e.g., northern geographical position, wine regulatory frameworks, local environmental features) interacting with the regional oceanic climate. Those climate and other non-climate related variables brought about significant changes in winegrowers' decision-making and management practices, varying greatly over time and space. Changing viticultural practices have enhanced winegrowers' adaptive responses, which are primarily reactive (e.g. harvesting, winemaking) or anticipatory (e.g. canopy and soil management) to short-term climate conditions. Winegrowers described changing trends in climate- and grapevine-related variables, where modifications in vine behavior were attributed to regional climate changes and evolving viticultural practices. With regards to future climate trends, winegrowers' displayed a great uncertainty, placing the most urgent adaptation priority on short-term strategies, while changing grapevine varieties and using irrigation were identified as last resort strategies. The study concludes by discussing the implications of these findings in the context of climate change adaptation in viticulture.

# The french wine AOC and the challenge of climate change

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The concept of AOC, set up in 1936 by the French authorities, is based on the existence of a strong link between wines and their terroir: the AOC wines presents specific characteristics, exclusively due to a particular geographical environment with its inherent natural and human factors**.** In 2015 France includes 360 wine AOCs, spread over its entire territory. To qualify for AOC each producer must comply with all production conditions proposed collectively by all producers and approved by the INAO and the Public Authorities. **A**ll AOC will have soon to answer to several challenges, such as the alcohol content of wine (correlated with public health policies), or the reduction of inputs (related to environmental societal concerns). The AOC also will have to answer to the challenge of climate change: if adaptation measures are insufficient, the result will be a significant changes in characteristics of the wines : higher alcohol content wines, modification of other characteristics of wines (acidity, tannic structure, ...). Furthermore the likely increase of extreme weather events (drought, heat waves, and even heavy rainfall) must already be taken into account by the producers, the vineyards being planted for several decades.

They will also have to adapt their farming practices to limit the consequences of climate change: change of vine control system with evolution of leaf / fruit ratio, reflection on weed, ... allowing in a first time to master the consequences of climate change. In a longer term the introduction of plant material (rootstocks, varieties) more suitable for extreme drought conditions, and/or with a longer growing season (in order to avoid the grape harvest at the height of summer, which in turn will warmer), will be studied. Like other economic sectors, AOC producers will probably be exhorted to reduce greenhouse gas emissions related to the production cycle, like promoting carbon storage in the soil of their plots.

In conclusion AOC producers, through their professional organizations, will be invited to appropriate as soon as possible the topic of climate change, and to consider a strategy to limit its consequences. The different evolutions of production conditions shall be preliminary tested with experiments, to ensure that the products obtained always fit with the characteristics for which each AOC was initially recognized.

# Climate change: issues and actions for the Bordeaux wine industry

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Bordeaux wines industry, based on 115,000 hectares of vineyards, 6,600 AOC wineries and 300 wine merchants firms, is investing for more than 10 years in the acquisition of knowledge related to adaptation to climate change. So far, climate change has been generally positive to the quality of Bordeaux wines (maturity, health status , ...). Nevertheless the advance of the growing season, higher temperatures or limitation of water resources would require the reconsideration of the practices to maintain the quality and the typicity of our wines. Solutions exist or are under evalutation in the vineyard: management of the leaf area to fruit ratio, canopy management, plant material, ... The difficulty will be to encourage the evolution of the practices at the right speed and on the entire vineyard. This presentation will summarize the current and possible adaptations for the Bordeaux vineyard.

# Adaptive Capacity for Climate Change Adaptation in the Wine Industry: Concepts and Measurement

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Climate change is significantly impacting the international grape and wine industries. Wine regions throughout the world are experiencing climate change through the gradual alterations in growing seasons, temperature, and precipitation, but also through the occurrences of extreme weather events that have negative consequences for quality wine production. These impacts are varied, and very dependent on location, but include increased grapevine/bud freeze damage, alterations in berry maturity and composition profiles, increased disease and pest pressures, reduced yields, and excessive alcohol concentration in wines. Future climate predictions indicate a greater frequency and intensity of extreme weather events along with the movement of optimal wine production areas pole ward, costal, and to higher elevations.

Against this backdrop, adaptation to climate change is occurring in several wine regions, however a comprehensive assessment of the factors affecting the adaptive measures is yet to be conducted. Adaptive capacity encompasses multiple elements necessary for adaptation to occur, and the access a wine region has to these resources can strengthen or undermine its overall capacity to adapt to climate change. The main objective of the current study was to develop a conceptual framework for assessing the adaptive capacity of a grape or wine region, and apply it to the Ontario wine industry.

The framework derived consists of a three-tiered structure, comprising eight strategic and operational determinants (financial, institutional, technological, political, knowledge, perception, social capital, and diversity). A comprehensive questionnaire was created from this framework that consists of 26 statements to which industry participants (42 Ontario wine industry members) indicated their level of agreement on Likert scales. The results indicated that the determinants related to perception, diversity, and knowledge had the highest degree of capacity, while technological and political determinants show the least. Grapegrowers and winemakers gave different patterns of responses, although overall, industry stakeholders were aware of both negative and positive impacts climate change could have on wine production. Our findings are discussed further in the context of opportunities to enhance adaptive capacity in the Ontario grape/wine community, and the applicability of this new tool to other wine regions around the world.

# Adaptation Strategies of Bordeaux's winemakers to face climate change

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According to the fourth evaluation report of the Intergovernmental Panel on Climate Change (IPCC), "global warming is undeniable" (IPCC, 2013). Schultz (2000) has been the first one to really assess the impacts of climate change on viticulture. Vineyards are particularly sensitive to climatic factors, notably to temperature and precipitation. Changes in historical and future average temperature are expected to influence the overall quality of wines, and climate changes present significant challenges for this industry, now and into the future (Ashenfelter and Storchmann, 2014)

Almost nothing is known about the potential responses and efficient adaptation strategies of wine growing regions to these different changes. Yet there is no doubt that climate change scenarios will cause major upheavals in the global wine growing sector, be it in terms the spatial distribution of vineyards or wine growers' practices. Although Hannah et al. (2013) have been predicting a 25 to 73% decrease in winegrowing areas by 2050 (*ceteris paribus*, without any adaptation), there is a need to analyze how the wine producing firms will adapt their strategies for wine production. This raises several questions, including which are the most effective and/or preferred strategies related to the expected changes; what are their determinants; and how are winemakers to be supported as they embark upon this change trajectory. But so far, there seems to be a lack of interest in analyzing adaptation strategies at firm level, the latter being nevertheless essential to study the future of the wine industry in the long run.

From this perspective, we conducted an original survey (2014) with a focus on two particular groups of *appellations* (*Bordeaux-Bordeaux Supérieur* and *Saint-Emilion*) on adaptation strategies of Bordeaux wine producers. The aim is first to highlight whether grape growers are aware or not about climate change and whether they manage it in the short and long run. Then, our work consists on identifying different types of (long and short term) adaptation strategies for different vintages in relation to their economic and structural drivers. A probit model is first developed to analyze the drivers (including economic, environmental, structural and, technical variables) that could explain whether or not wine producing firms take into consideration in their short run production decisions the impact of climate change captured by the so-called run effect "*effet millésime"*. Then, a multivariate correspondence factor analysis (CFA) is conducted to characterize the types of adaptation behaviours for different and specific vintages in Bordeaux.

We show that wine producers are really aware of climate change. In our case, the results demonstrate a significant short-term adaptation of wine producing firms, technical for the main part of time (more than during the vinification process or the commercialization) and in relation with the characteristics of each specific vintage. Wine producers therefore seem to include every year the vintage in the development of their technical management strategies. Finally, we also show that wine producers in their responses to the survey tend to make contradictory statements and arguments concerning the implementation of longer term adaptation strategies to cope with climate change, and more especially all issues and questions dealing with the modification of *appellation* specifications.

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# Adaptation Strategies to Climate Change in the French wine industry: The role of networks connecting wine producers and researchers

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Recent works in innovation economics suggest that firms adaptation to Climate Change (CC) will depend on their capacity to build and share knew knowledge at regional level, and therefore to create efficient local networks supporting such a learning process (Rosenzweig,Wilbanks 2010). The relations between firm managers and research centers or universities are supposed to play a key role in these networks (Giuliani, Morrison 2010). This issue is particularly relevant in the case of the wine industry, which is structured into different regional vineyards, each of them being impacted by climate change (Holland, Smit 2010, Viguier et al. 2014). In this communication we analyze the adaptation strategies of wine producers in three French vineyards (Bordeaux, Champagne, Languedoc) and how these strategies can be supported by the construction of networks between wine producers and researchers or engineers working in R&D organizations. We characterize these strategies by three analytical dimensions : i) the perception by the actor of the CC issue, ii) the development of new actions or practices responding to this issue, and iii) the construction of personal networks in order to access to information on wine and CC. Our hypothesis are that i) these networks are built by both the producers and the researchers, involving intermediary actors and mediations, and ii) these networks depend on different factors including personal characteristics of both producers and researchers and inherited regional institutions, with a specific role of "regional wine interprofessional organization".

A "two side survey" has been conducted in Languedoc, Aquitaine and Champagne: on one side, 87 producers of AOC wines were asked on their perceptions of CC, their changes of practices (variety, location of plantation, agronomic practices, enology…) and the relationships they have used in order to get knew knowledge for these changes ; on the other side, 94 researchers and engineers (in the 3 regions, from Inra, University, IFV, Agriculture chambers or interprofessional organizations) were asked on their involvement in the production of knowledge on CC and the social networks which are connecting them to the wine producers. We codify the answers with criteria representing both the actors strategy (including self-centred networks) and potential explicative variables, which influence have been statistically tested.

Our main results show that both the perception of CC by wine producers and the network they built to improve their knowledge are statistically different according to the region. Personal trajectory (education, professional responsibility) and production patterns (conventional, organic or high quality wines) also influence the adaptation strategies. On the other side the researcher's involvement in knowledge production on "wine and CC" is not sufficient to improve manager's adaptation to CC. The researcher propensity to contribute to CC adaptation is influenced by his research field, his regional location and his organizational affiliation. Finally, we discuss these results by referring to the Innovation Systems perspective. Both regional and relational dimensions of innovation systems emerge as a relevant lever for climate change adaptation.

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# "Is global warming desired by wine consumers?"

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Many studies consider that Global warming (GW) will have significant consequences on the chemical composition of grapes harvested. Hence the characteristics of wines with a certification of origin may change considerably. In this paper we argue that, following the strategic choices of some producers delaying the harvest date and the grapes maturation, these "GW wines"are in fact already available on the market. Hence we propose a lab experiment using both sensory analysis and experimental auctions in order to elicit the consumers' evaluation of these wines. We show how consumers are affected by the different sensory characteristics (visual, olfactory and gustatory) and we find instability of preferences, with a final hierarchy detrimental to the GW wines.

The experimental plan began with the selection of three different wines within the same appellation of origin (AO) in Bordeaux. We chose an AO where the variety "Merlot" is the most commonly used grape because this variety is well known to be extremely sensitive to global warming. In a sensory analysis laboratory 48 experts (professionals and oenologists) evaluated 30 red commercial wines from the 2010 vintage. This evaluation was essentially olfactory according to the typicity of the wines and the expressions of overripe grapes (*e.g.* jammy fruits). Using the 'Majority Judgment' technology (Balinski and Laraki, 2013) we then selected two wines which are much appreciated by experts but diametrically opposed according to GW symptoms: wine A was the one with the lowest intensity of overripe grapes (i.e. the "regular" wine of the AO); wine B with the highest intensity (*i.e* the "GW wine"). We select also a wine C asan intermediary wine, in relation to these criteria. Then we proposed these three wines to 184 consumers after adding a 'pirate wine'A', created from wine A, by an artificial addition of ethanol, in order to find the exact level of ethanol percentage contained in the wine B. The experimental design combines both sensory analysis and experimental auctions in order to measure the hedonic perception for different characteristic wines and to revel the willingness to pay (using the current BDM mechanism) for each wine and for different levels of information (Lange et al., 2002; Combris et al., 2009). The main originality of our experiment is the introduction of habit's effects. The model shows the ability of consumers to discriminate wines and justify their choice based on the global warming descriptors. We also show how to perform the various anchors of consumers throughout the growing assessment information.

Finally, we show the fragility of judgments that can have on the short term. Therefore we conclude that it is essential to allow time for consumers to evaluate different wines in a familiar atmosphere, if we want to collect truly revealing information for structuring and repeat purchases. We conclude with lessons learned from the producers' strategies and their interest/ability to reactagainst global warming.

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# Reducing the impact of greenhouse gases on the wine sector: situation in France and approach by the OIV

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In 1896, the Swedish scientist Arrhenius had envisaged a global warming due to the burning of fossil fuels in order to fight against the return of the ice. Since, the scientific community of the Intergovernmental Group of Experts on Climate Change (IPCC) has established a strong link between global warming and the greenhouse effect. Foresight is a difficult exercise subject to many uncertainties. This is especially true for the climate influenced by many factors, warranting caution is required in interpreting developments. However, the warming seems inevitable. In view of current developments measured for fifteen years (changing the order of 0.5 ° C), it seems plausible to imagine significant changes for the future.

The limitation of greenhouse gas emissions can result from an international approach since the enhanced greenhouse gases effect is a global phenomenon independent of the place of emission of gases. In view of recent developments, it seems likely that the control of greenhouse gas emissions become a growing concern in the coming years, with consequences that will be even better managed they have been well anticipated.

Viticulture will not escape from climate change. Beyond the adaptation of viticultural and oenological technical itineraries to this trend, the wine industry has to limit its impact on the greenhouse effect.

Developed by JM JANCOVICI on behalf of ADEME (French Agency for Environment and Energy Management) and the MIES (Interministerial Mission for the Greenhouse Effect) in 2003, Bilan Carbone method is a method to quantify the contribution of a company to the greenhouse effect. It takes into account the six families of greenhouse gas (GHG) included in the Kyoto Protocol. There are 3 three possible approaches according to the perimeter as desired, characterized: 1- Internal or legal basis, for direct emissions called energy (related to the use of energy, fossil or electric) and the so-called non-energy (related to the use of nitrogen fertilizers and leakage of refrigerants); 2- The intermediate perimeter or added emissions, taking into account some of the transport (internal cargo freight to customers, customers to exploitation, transport commuting employees, employees of transport-related missions), manufacturing of inputs, including purchase of grapes, as appropriate, as well as all the services charged to operations; 3- The overall perimeter or Bilan Carbone, which is the comprehensive consideration of all emissions attributable to operations, including the transport of inputs, construction of buildings, waste management and wastewater, the Amortization of capital assets. This tool allowed to perform measurements in various French cases and served as support to develop climate plans in several French wine regions: Bordeaux, Burgundy, Champagne. A summary document and extension was published IFV http://www.vignevin.com/publications/collection-itineraires.html. Within the International Organization of Vine and Wine, a first resolution was finalized, providing the general principles of OIV protocol for calculating the stock of greenhouse gases for the wine sector http://www.oiv.int/oiv/info/enresolution?lang=en If contain information on the approach to scale companies and the industry products. In addition work is currently underway to publish particular Appendices for supplying a database and harmonize methodologies internationally. The communication aims, from the examples and methodologies, to shed light on this issue and propose operational actions to be implemented within the wine industry to reduce its impact on the greenhouse effect. A particular development focus on the inclusion of the greenhouse effect in the treatment of winery effluents comparing different systems applicable.

# *SESSION 4 : Perception and adaptability of climate change by the actors*

## *POSTER*

# Perception of irrigation practices by wine consumers in a context of climate change.

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According to the actual simulations, there is a general agreement that water deficit will increase and all phenological stages of vines will occur earlier in the future due to climatic change. These major events are expected to have significant repercussion in many aspects, leading to changes in the geographical distribution of vineyards and in wines typicality. In this sense, some terroirs estimated today as the best plots might become less favorable for the qualitative development of vines. Moreover, vines could be even planted on plots until now evaluated as less qualitative due to an excessive water holding capacity.

Against this backdrop, winegrowers must adapt their practices to preserve quality and typicality of wines or accept the consequences of a changing climate. However, flexibility in the adaptation of cultural practices will depend on the type of product e.g. a DOP wine, and therefore irrigation is possible only in certain cases. At short and medium terms, climate change might be controlled with the adaptation of different cultural practices and without considering irrigation. However, at long term, qualitative irrigation seems to be the most systematic, if not the best, cultural practice for dealing with climate change.

The objective of this work is to evaluate consumer's opinion about the impact of irrigation on the perceived quality of wines, in order to provide useful information to professionals and researchers of the industry. The work was conducted in 2015 from 512 surveys on Internet. The methodology is based on previous works that show the relevance of the concept of "consumer's involvement" and the concept of "involvement in environmental issues" as a criterion for consumer segmentation and so; this segmentation was used to analyze the responses. Results show a-priori that levels of involvement in wine and in environment are related: consumers less involved in wine tend to be not involved in environment issues. Moreover, consumers involved in wine could be divided in two groups: those less likely to incorporate irrigation practices and those who are favorable and are even willing to pay higher or similar prices for wines issued from irrigated plots. Furthermore, the level of implication in wine seems to play a role in accepting irrigation; consumers not implicated on wine don't have a formed opinion whereas implicated consumers showed both for and against a reasoned irrigation as a tool to deal against climate change. Moreover, within consumers implicated in wine, age could serve for explaining the acceptance of irrigation since seniors consumer (≥65 years old) were less favorable to accept irrigation and wines varieties modification but more likely to accept a plot relocation in order to maintain quality. On the other hand, young (≤35 years old) and medium consumers (from 36 to 64 years old) were more likely to accept irrigation and a different grape variety to preserve wine quality.

In the current scenario of climatic change, producers needs to decide the best way of dealing with changes in wine typicality and quality. In this sense, results can help producers to understand climatic change from the consumer's perspective in order to best adapt theirs marketing and technical strategies. A good communication adapted to consumer's age and level of implication on wine seems crucial to be implemented.

# Ecophysiology of grapevine and adaptation to the environmental constraints in vineyards of South America

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Relatively few comprehensive studies dealing with climate change in vineyards of South America have been conducted (Price Waterhouse Coopers, 2009 ; Quenol et al., 2014). Within the framework of a Master module of the Faculty of Agrarian Sciences of the University of Comahue, Neuquèn, - Argentina, in 2013-2014 a research task was carried out by groups of students on adaptations of viticulture to environmental constraints, including climate change. This work focused on five vineyards of South America, namely Neuquén and Cafayate in Argentina, Tarija in Bolivia, Bio-Bio in Chile, and Canelones in Uruguay. It dealt with the characterization of the physical factors of each area of study, the main environmental constraints, a prospective of climate evolution according to scenario A1B (~RCP 6) of GIEC 2013 and a justification of the adaptation strategies suggested at various space and temporal scales.

The results show very contrasted situations related to the environmental and socio-economic local conditions which make that the concerns of the actors differ greatly from one vineyard to another. The recommended strategies of adaptation take into account at the same time the evolution of annual practices (soil and foliage management, protection against climatic and phytosanitary risks, management of grapes at harvest…) and the evolution of perennial practices (choice of plant material, choice of site and techniques of irrigation…), both at the individual and collective levels. In addition, a great importance is given to the aspects of marketing (type of products, markets…) as well as public policies regarding infrastructures (transportation routes, water management), research, formation and access to the financing.

Acknowledgments. Groups of students : 1-Neuquen : Gandolfi S.C., Esteves J.M., Tello Najul R.G. Oehrens Kissner P.A., Landerreche, S. ; 2-Canelones : Moreno Z., Sanchez A.D., Mantegna M.M., Martín V.A., Vita L.I. ; 3-Bio Bio : Pastrana, M.M., Pero E., Sessa A.M., Lodolo X.V., De Arregui J.A. 4-Tarija : Salaberry J.M., Simes A.B., González Flores M. 5-Cafayate : Fernández C.J., Maero E., Prieto G. C., Gresia J.A., Vullioud M.B.

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# Researches on "Innovative" "Sustainable" political, technical, production process and product, communication and marketing solutions aimed at helping to overcome the problems caused by climate change in Veneto and Friuli-Venezia Giulia (Italy North East).

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After presenting 1- a basic work on the urgent need to use correct definitions and expositions, as well as assessments "Universal or MetaEthical 4C" of "Sustainability", "Quality", “Typicality” of "Terroir", "Zoning ", " Territoir " and " Innovation ", also, in the wine sector with regard to climate change, a 2- 'other work which showed that climate change is a great opportunity to improve all viticulture, even, according "Great Chain MetaEthics 4C" of Conegliano Campus 4C, 3- in this work will show the results of research conducted to help overcome the problems caused by climate change in relation to our area, [Veneto and Friuli-Venezia Giulia (Italy North East )], according to the philosophy, methodology of the "Great Chain MetaEthics 4C" of Conegliano Campus 4C, our computerized algorithm which considers in harmony with each other "all" technical, economic, environmental, social-employment, existential, ethical " MetaEthical 4C" factors.

Research was conducted and mutually coordinated for Veneto and Friuli-Venezia Giulia (North East of Italy) and involved aspects of policy, "territoir", "terroir", "zoning ", global production models, communication and marketing, and more.

From research conducted in Veneto and Friuli-Venezia Giulia in the light of the current "significant" climate change and official information on future climate change had emerged that by acting in an innovative way according to our logo "A step back to the future" on "territoir", "terroir", " zoning ", global production models [land preparation, genotype, planting layouts, types of cultivation, pruning, management of: soil, plant (roots, trunk, vegetative apparatus and production) harvest, pest harvest and management, "quality", "typicality" and other innovations in product and process], on communication and marketing, and in addition to them, it was possible for the Veneto and Friuli-Venezia Giulia , and not only overcome the problems caused by climate change.

Therefore these positive results are encouraging for the future, not only for these and similar areas but also for those to the southern and to the northern grape growing areas.

# VIVA Sustainable Wine: the Italian label on sustainability performances

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In 2011 the Italian Ministry for the Environment, Land and Sea has launched the National pilot project VIVA "Sustainable Wine". The purpose of the project is to improve the performance of sustainability in vineyards and wine production through the development of a certification system, based on the use of four indicators: Air, Water, Territory and Vineyard.

The indicators evaluates the impact of wine production taking into account the three pillars of sustainability (Corbo et al., 2014). "Air" evaluates the greenhouse gas emissions directly and indirectly related to the life cycle of a product (CFP) or to an organization (GHGI) (Lamastra et al., 2012). "Water" reveals the total volume of fresh consumed and polluted water both referred to company activities or to the production of a wine bottle (Lamastra et al., 2015). "Vineyard" takes into account the agronomic management practices in the vineyards (use of pesticides and their effect on water bodies and soils, soil management practices, fertility and biodiversity issues (Maurino et al., 2013). "Territory" is a kit of qualitative and quantitative indicators, built in order to evaluate the actions undertaken by the companies and their impact on the territory.

The results of the sustainability assessment are communicated to the consumers with a label (available through internet or smartphone/tablet) that summarizes the results and improvements, in terms of sustainability, achieved by the wine companies.

The pilot phase, conducted with the scientific collaboration of the Research Centre for Sustainable Agriculture OPERA, involved a number of major Italian wineries, which were selected based on their geographical location and the products they produce. This phase was completed in 2014 and led to the definition of technical specifications for sustainable wine production, that now serve as a reference for companies who want to achieve the validation foreseen by the project.

In the poster presentation, the results of companies' sustainability assessment are presented and discussed, as well as the improvements in terms of sustainability performances achieved thanks to their participation in the VIVA Project.

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# Building the stakeholder platform to foster sustainability in the wine sector

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Consultation, coordination and collaboration are essential to achieve sustainability. Sharing existing knowledge and disseminating new technical solutions, indeed, are considered essential to foster synergies and cooperation between the various actors in the wine value chain, in order to ensure that all the players can have the tools to improve the environmental, economic and social sustainability of wine production (Capri et al., 2014).

The neonate WOS - Wine Observatory Sustainability (www.wineobservatorysustainability.eu) - is an international no-profit web platform on sustainable wine, aiming to foster sustainability in the wine sector through cooperation and coordination between the various actors in the wine value chain. In particular, WOS aims:

- to create an international network and to build a base for useful synergies, involving all people and main organizations working on the issue of sustainable development of the wine sector;
- to share and combine experiences, programs, initiatives from different countries and actors about sustainability of the wine value chain;
- to sensitive to the topic all the players in the wine chain (including the consumers), sharing events, documents, training and initiatives on the topic of sustainability in the wine sector;
- to promote a dynamic environment where web users are actively involved in its development.

In order to achieve these objectives, the platform include and connect the most relevant practical tools, recognized authorities and best practices. The platform address all the players in the wine value chain, working and promoting sustainability through specific projects (at whatever step of the chain, including consumers). WOS activity is constantly supervised by committees of experts. First set of materials have been included looking at the available state of the art literature (Pomarici et al., 2014; Corbo et al., 2014).

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http://www.wineobservatorysustainability.eu

# Perception of climate variability and vineyards vulnerability in a coastal wine region in South America

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Over a wine region, knowledge of climate variability is primordial to contribute adaptation issues to climate change. In the wine region of southern Uruguay, the spatial variability of temperature is stronger than temporal variability, due to the influence of La Plata River and different topographic situations. This study had three hypotheses: 1) wine growers of southern Uruguay know the local temperature variability; 2) grapevine cultural practices were changed over the last 20 years and part of it was in function of local and temporal variability of climate; and 3) the evolution of those practices could lead to determine the vulnerability of farming systems to local and regional variability. Interviews were carried out using the method developed in TERADCLIM Project to evaluate wine growers perception and adaptation of climate change. The main results showed a clear perception of climate variability for the wine growers, especially of annual variability. Extreme climate events occurred the last years were highlighted in the interviews (precipitations with strong winds, hails), from which 71% considered an increase of frequency of those events. Soil management was the principal practice that was modified over the studied years. The intensity of tillage had evolved from high intensity to minimal tillage and a decrease of herbicides utilization. 43% coincided that the evolution of some viticulture practices could be due to climate. To determine the vulnerability of the farming systems over the wine region, we elaborate matrices of sensitivity and adaptive capacity from the interviews results. Matrices of sensitivity, considered by a biophysical origin, were elaborated with internal and external factors from the wine grower point of view. Internal factors were variety, pruning system, canopy management, soil management, grape thinning, training system and grape final destination (table wine or high quality wine). External factors were soil type, topography and final price of grape. The matrices of adaptive capacity of wine growers were related to access to technical advice, communication and services, possibility of grouping, technology adoption and type of exploitation (familiar or not). To decrease vulnerability of grapevine, type and date of pruning (to reduce frost risk), canopy management (to modify micro-climate) and soil management (in high water availability situations) were highlighted. When adaptive capacity of wine growers was lower, grouping with others wine producers, including for technical assistance, led to decrease vulnerability too. Those results are useful to identifying the *savoir-faire* of wine growers, who are able to adapt constantly their practices to the local annual climate variability, and thus, provide adaptation measures to climate change.

# The viticulture and oenology in XXI century, the value of landscape

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Viticulture, beyond the primary production, provides valuable ecosystem services; from supporting services, through the easily documented provisioning service, to the important regulating and cultural services (Clothier et al., 2013). The wider landscape scale of terroir also needs to be considered. This involves the productivity and sustainability of the agro-forestry surface of the catchment areas that are needed to supply external resources of water, energy and nutrients, and to consider the chemical composition of wastewaters from different origin, along with the emissions and sequestration of greenhouse effect gases. Increasingly, this will be the way of sustainable production in the Twenty First Century. It will become increasingly evident when viticulture is placed at the landscape level, and will require understanding landscape ecology as a representation of the intricate network of regulating services and the biodiversity status of landscapes. This ecosystem services approach, along with the knowledge of the provisioning services of high quality of wines, compiled during XX century, provides an assessment of the valuable economic benefits. However, in the XXI century, our society and viticulture must change to become a new and important source of opportunities for related sectors and the whole community. Viticulture must become eco-efficient in the use of resources and sustainable. It must maintain and leave a heritage and conservation of resources for the future, because resources are scarce and finite.

IRTA proposal for viticulture in XXI century, affected for climate and global changes, is focused in technological options that analyze how farming management concepts, practices and technologies, including plant breeding, could enable sustainable intensification of crop production, with the aim to increase grape production and support wine supply. The aim of sustainable intensification is to produce more production from the same area of land while reducing the environmental impacts, under social and economic beneficial conditions. This proposal addresses agriculture in developing countries as well as in industrialized countries (Europe), small-scale and large-scale farming, extensive and intensive agricultural production systems, and low and high tech production practices, can provide adaptive and mitigation strategies for this crop, for this important landscape in Europe.

# *AUTHORS INDEX*

# The Wine list of ClimWine Symposium

April 10>13, 2016 – Bordeaux, Fra

## Thank to all the partners who graciously provided the wines for this conference

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