

# *les dossiers* d'**AGROPOLIS** INTERNATIONAL

*Expertise of the scientific community  
in the Languedoc-Roussillon area (France)*

## *Viticulture and Wine*

Number 21  
October 2016

# AGROPOLIS INTERNATIONAL

agriculture • food • biodiversity • environment

**Agropolis International** brings together authorities of research and higher education in Montpellier and Languedoc-Roussillon in partnership with local communities, companies and regional enterprises and in close cooperation with international institutions.

This scientific community has one main objective—the economic and social development of Mediterranean and tropical regions.

**Agropolis International** is an international space open to all interested socioeconomic development stakeholders in fields associated with agriculture, food production, biodiversity, environment and rural societies.

Agropolis International is an international campus devoted to agricultural and environmental sciences. There is significant potential for scientific and technological expertise: more than 2,700 scientists in over 75 research units in Montpellier and Languedoc-Roussillon, including 400 scientists conducting research in 60 countries.

Agropolis International is structured around a broad range of research themes corresponding to the overall scientific, technological and economic issues of development:

- Agronomy, cultivated plants and cropping systems
- Animal production and health
- Biodiversity and aquatic ecosystems
- Biodiversity and land ecosystems
- Economics, societies and sustainable development
- Environmental technologies
- Food: nutritional and health concerns
- Genetic resources and integrative plant biology
- Grapevines and wine, regional specific supply chain
- Host-vector-parasite interactions and infectious diseases
- Modelling, spatial information, biostatistics
- Water: resources and management

Agropolis International promotes the capitalization and enhancement of knowledge, personnel training and technology transfer. It is a hub for visitors and international exchanges, while promoting initiatives based on multilateral and collective expertise and contributing to the scientific and technological knowledge needed for preparing development policies.

## Training, research and innovation expertise on viticulture and wine at the scientific research platform in Montpellier and area

This Dossier presents the scientific structures based in Languedoc-Roussillon area, members of the Agropolis International scientific community, whose activities are focused on training, research and innovation regarding viticulture and wine:

- higher education and research institutions, development and incubation platforms
- 14 joint research units (UMRs, attached to several parent organizations) and research groups, conducting studies in different complementary scientific disciplines (genetics, physiology, agronomy, ecology, oenology, economy, information science, etc.)
- 3 joint technology units (UMTs), experimental units and field stations, conducting studies in the field or in technology centres for research units and public and private partners.

**This special issue showcases the broad range of training, research and innovation expertise of regional stakeholders in the fields of viticulture and wine.**

Scientifically, based on practical examples in five main thematic areas:

- analysis of the diversity and functioning of the grape genome
  - vineyard management, agricultural practices, impact reduction
  - knowledge to control wine quality
  - social science, innovation and sectoral transformation approaches
  - meeting digital challenges in the sector
- and a cross-cutting chapter illustrating how—through transdisciplinary programmes—climate change adaptation and sustainable vitiviniculture challenges can be addressed by combining these skills and expertise.

This Dossier also highlights the broad scope of partnerships developed by regional scientific stakeholders with the academic sector in France, Europe and worldwide, and with the private sector to support and facilitate top notch research and training, so as to meet the needs of stakeholders in the sector, and of consumers, while fostering innovation.

The range of diploma training-education courses (2-5 years of higher education) offered by Agropolis International member institutions in the viticulture and wine sectors are also presented.

# Viticulture and Wine

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# Foreword

**A**gricultural research and training conducted in Montpellier (France) are tightly linked with vine growing and winemaking. At the heart of the large Languedoc wine-growing region, scientists (researchers and teachers) have long been focusing on issues related with this production, especially at times of crisis or development opportunity. These scientists were the first to identify phylloxera, the pest that devastated vineyards in France in the late 19<sup>th</sup> century. They subsequently proposed solutions against this scourge, especially via grafting onto resistant American hybrid vine plants, which ultimately saved European viticulture. Jules Émile Planchon and Gustave Foex, respectively former professors at the *Faculté de Pharmacie* (now the *Université de Montpellier*) and the *École Nationale d'Agriculture* (now Montpellier SupAgro), marked the history of vitiviculture through these successes. Agricultural research and teaching were then mutually strengthened for more than a century, while developing training areas and scientific disciplines relevant to vineyard management, winemaking and wine marketing.

This research was punctuated by a series of issues, ranging from disease control, mechanization and enhancement of yield and quality to winemaking and market management. These issues now mainly concern the environmental and socioeconomic sustainability of vineyards, the tailoring of wines that meet consumer expectations, in addition to reductions in pesticide use and adaptations to climate change.

The platform set up in the sphere of Agropolis International, and led mainly by the French National Institute for Agricultural Research (INRA), Montpellier SupAgro, *Université de Montpellier* (UM) and the National Research Institute of Science and Technology for Environment and Agriculture (IRSTEA), has mobilized over 130 scientists on these issues. Local research/development and experimentation stakeholders such as the French Institute for Vine and Wine (IFV), the *Institut Coopératif du Vin* (ICV Group), chambers of agriculture and many start-ups—all closely associated—are also involved. Agropolis International is thus now one of the leading international research and training platforms on viticulture and wine while clearly having substantial potential for further progress.

Studies conducted by a dozen joint research units on viticulture and wine are firmly underpinned by a full spectrum of scientific disciplines: plant science, agronomy, processing science, mathematics and social science. This disciplinary support is essential for knowledge building on scientific fronts and ensuring the consistency of targeted research programmes for the sector. Research carried out by teams working on viticulture and wine is geared towards enhancing knowledge on the grape genome, the response of vine plants to stress, the biogenesis of compounds in grapes (for different grape crop uses), soil erosion and input dynamics, yeast physiology or the physicochemical characteristics of wines. Issues regarding the organizational aspects of the sector, its regulation and market functioning are also investigated. The continuum of disciplines involved in the platform has also enabled the development of integrated approaches to address major challenges facing the sector. The expertise of the teams is thus utilized in interdisciplinary programmes focused on complex prospective issues, such as climate

change adaptation, grapevine dieback, the development of sustainable cropping practices or the management of alcohol and acidity levels in wines.

Management of these projects is facilitated by the availability of resources and infrastructures of excellence, especially a globally unique grapevine germplasm collection that pools exceptional genetic resources, a high-throughput plant phenotyping platform, a polyphenol analysis platform, as well as a technology centre for winemaking. These highly internationally appealing features have led to unprecedented advances in research programmes while supporting the international outreach objectives of Agropolis.

Moreover, the Labex Agro Laboratory of Excellence, coordinated by *Agropolis Fondation*, supports the structuring, aspirations and scope of the scientific community. It is focused on plant science and sustainable agriculture.

The viticulture and wine research carried out is highly receptive to concerns and involvement of the business world, with many projects carried out within the framework of partnerships with industry, technical institutes, interprofessional stakeholders and other organizations in the sector. Links with IFV have thus been strengthened via three joint technology units (Geno-Vine, QUALINNOV and ECHOTECH-VITI), which are essential interfaces for the transfer or co-construction of innovations for the sector. Moreover, the research benefits from the *Qualiméditerranée* competitive cluster and various services that facilitate their activities, such as *Agro-Valo Méditerranée* for INRA and Montpellier SupAgro.

Viticulture and wine research of the platform has mainly been developed in a cooperation setting through scientific programmes at regional, national and international levels. The teams are involved in several emblematic projects and networks (LACCAVE and INNOVINE projects\*, FIDELÉ joint technology network\*\*\*, etc.). They are regularly incorporated in international research and training networks with major centres in different wine-growing countries—University of California (Davis), American Association of Wine Economists, Australian Wine Research Institute, OENOVITI International, the *Groupe international d'experts en systèmes vitivinicoles pour la Coopération*, the European Master of Science of Viticulture and Enology (EMaVE Consortium), the *Association universitaire internationale du vin* (AUIV), etc.

A bibliometric analysis of recent publications (see *figure next page*) highlighted the wealth of collaborations with other research centres in France, especially with the Bordeaux platform. These two platforms complement each other, thus enhancing their international appeal, through joint scientific initiatives, co-supervision of PhD thesis candidates and co-certified international Master's candidates.

Education and training programmes for engineers, oenologists, BSc, MSc and PhD candidates attract students from around the world, who come to acquire advanced knowledge and a business-friendly interdisciplinary and international culture. In a setting of constant technical progress and a highly specific regulatory framework, the expertise of these graduates, engineers, researchers and teachers is regularly tapped by institutions in the

viticulture and wine sector at regional, national and international scales.

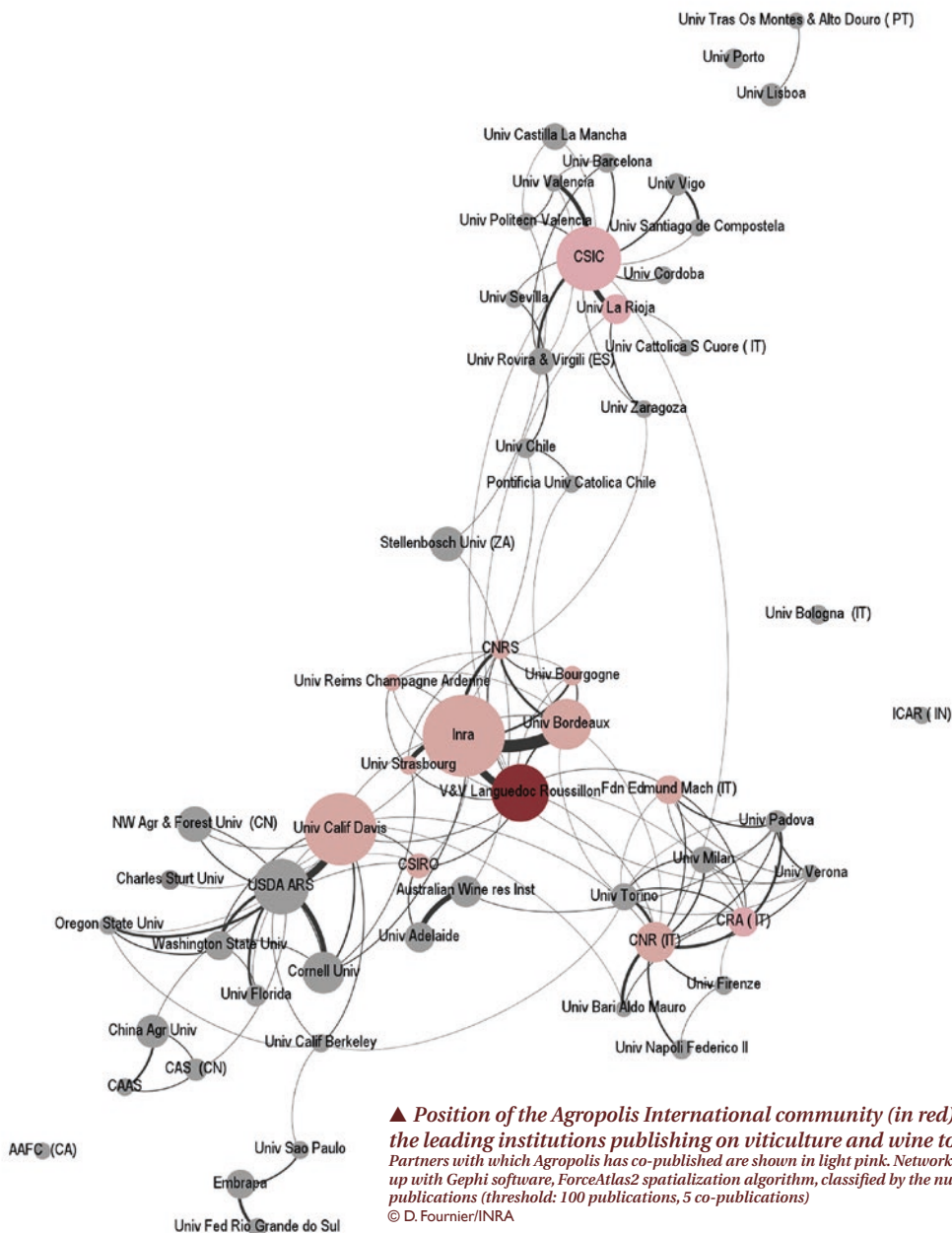
This Agropolis International Dossier is designed to enhance awareness on the wealth of training programmes and the diverse range of research topics focused on in the laboratories of the viticulture and wine platform in Montpellier. The overall thrust is to improve the structure and visibility of this platform. It aims to showcase the initiatives under way to organizations in the sector, businesses and local authorities, to facilitate the development of links with other research and training stakeholders of the national and international scientific community and those involved in research and development. It could thus be of interest to all sectoral stakeholders and students for which it is targeted.

The Dossier is organized in eight main chapters. The first four chapters address aspects related to grape genetic diversity, cropping systems, oenology, sectors

and markets. The next two present the mathematics and information science contributions, as well as integrated approaches implemented around major issues (climate change, sustainable viticulture and product diversification). While the last two chapters deal with the organization of partnership, innovation and training arrangements.

**Bruno Blondin, Hervé Hannin, Thierry Simonneau, Patrice This & Jean-Marc Touzard**

- \* LACCAVE Project: Long-term adaptation to climate change in viticulture and oenology.
- \*\* INNOVINE Project: Combining innovation in vineyard management and genetics for sustainable European viticulture.
- \*\*\* FIDELE joint technology network: fermented and distilled products.



# Topics covered by the research teams

(September 2016)

**R**esearch units and teams mentioned in this *Dossier* are listed in the following chart.

1. Analysis of grape genetic diversity and genome functioning
2. Vineyard management, agricultural practices, impact reduction
3. Knowledge for controlling wine quality
4. Economics of innovation and of the wine sector
5. Meeting digital challenges in the sector

The 'page' column indicates where the research unit or team is presented. Red dots (●) indicate the main topics focused on by the unit or team, while black dots (●) indicate secondary topics in which they are also involved.

| Research teams and units   | Page | 1 | 2 | 3 | 4 | 5 |
|--|------|---|---|---|---|---|
| <b>UMR AGAP - Genetic Improvement and Adaptation of Mediterranean and Tropical Plants</b><br>(CIRAD/INRA/Montpellier SupAgro)<br>Director: Patrice This, <a href="mailto:diragap@cirad.fr">diragap@cirad.fr</a><br>Contact: Jean-Pierre Péros, <a href="mailto:peros@supagro.inra.fr">peros@supagro.inra.fr</a><br><a href="http://umr-agap.cirad.fr">http://umr-agap.cirad.fr</a>   | 10   | ● |   |   |   |   |
| <b>UMR B&amp;PMP - Biochemistry and Plant Molecular Physiology</b><br>(INRA/CNRS/Montpellier SupAgro/UM)<br>Director: Alain Gojon, <a href="mailto:alain.gojon@supagro.inra.fr">alain.gojon@supagro.inra.fr</a><br>Contact: Isabelle Gaillard, <a href="mailto:isabelle.gaillard@supagro.inra.fr">isabelle.gaillard@supagro.inra.fr</a><br><a href="http://www1.montpellier.inra.fr/ibip/bpmp">www1.montpellier.inra.fr/ibip/bpmp</a>  | 13   | ● |   |   |   |   |
| <b>UMR CBGP - Centre for Biology and Management of Populations</b><br>(INRA/CIRAD/Montpellier SupAgro)<br>Director: Flavie Vanlerberghe, <a href="mailto:dircbcp@supagro.inra.fr">dircbcp@supagro.inra.fr</a><br>Contacts: Marie-Stéphane Tixier, <a href="mailto:marie-stephane.tixier@supagro.fr">marie-stephane.tixier@supagro.fr</a> & Serge Kreiter, <a href="mailto:serge.kreiter@supagro.fr">serge.kreiter@supagro.fr</a><br><a href="http://www6.montpellier.inra.fr/cbcp">www6.montpellier.inra.fr/cbcp</a>   | 27   |   | ● |   |   |   |
| <b>UMR Innovation - Innovation and Development in Agriculture and the Agrifoods Sector</b><br>(INRA/Montpellier SupAgro/CIRAD)<br>Director: Guy Faure, <a href="mailto:guy.faure@cirad.fr">guy.faure@cirad.fr</a><br>Contact: Jean-Marc Touzard, <a href="mailto:touzard@supagro.inra.fr">touzard@supagro.inra.fr</a><br><a href="http://umr-innovation.cirad.fr">http://umr-innovation.cirad.fr</a>   | 40   |   | ● |   | ● |   |
| <b>UMR ISEM - Institute of Evolutionary Sciences of Montpellier</b><br>(UM/CNRS/IEPHE/IRD)<br>Director: Agnès Mignot, <a href="mailto:agnes.mignot@univ-montp2.fr">agnes.mignot@univ-montp2.fr</a><br>Contacts: Laurent Boubry, <a href="mailto:laurent.boubry@univ-montp2.fr">laurent.boubry@univ-montp2.fr</a> & Jean-Frédéric Terral, <a href="mailto:terral@univ-montp2.fr">terral@univ-montp2.fr</a><br><a href="http://www.isem.univ-montp2.fr">www.isem.univ-montp2.fr</a>  | 16   | ● |   |   |   |   |
| <b>UMR ITAP - Information-Technologies-environmental Analysis-agricultural Processes</b><br>(IRSTEA/Montpellier SupAgro)<br>Director: Tewfik Sari, <a href="mailto:tewfik.sari@irstea.fr">tewfik.sari@irstea.fr</a><br>Contact: Bruno Tisseyre, <a href="mailto:bruno.tisseyre@supagro.fr">bruno.tisseyre@supagro.fr</a><br><a href="http://itap.irstea.fr/">http://itap.irstea.fr/</a>  | 48   |   |   |   |   | ● |
| <b>UMR LEPSE - Ecophysiology of Plants Under Environmental Stress</b><br>(INRA/Montpellier SupAgro)<br>Director: Bertrand Muller, <a href="mailto:bertrand.muller@supagro.inra.fr">bertrand.muller@supagro.inra.fr</a><br>Contacts: Thierry Simonneau, <a href="mailto:thierry.simonneau@supagro.inra.fr">thierry.simonneau@supagro.inra.fr</a> & Eric Lebon, <a href="mailto:lebon@supagro.inra.fr">lebon@supagro.inra.fr</a><br><a href="http://www6.montpellier.inra.fr/lepse/Presentation-generale">www6.montpellier.inra.fr/lepse/Presentation-generale</a> | 22   | ● | ● |   |   | ● |
| <b>UMR LIRMM - Montpellier Laboratory of Informatics, Robotics and Microelectronics</b><br>(UM/CNRS)<br>Director: François Pierrot, <a href="mailto:information@lirmm.fr">information@lirmm.fr</a><br>Contact: Philippe Vismara, <a href="mailto:philippe.vismara@lirmm.fr">philippe.vismara@lirmm.fr</a><br>Coconut team: <a href="http://www.lirmm.fr/coconut">www.lirmm.fr/coconut</a>  | 51   |   |   |   |   | ● |

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| <b>UMR LISAH - Laboratory on Interactions between Soil, Agrosystems and Hydrosystems</b><br>(INRA/IRD/Montpellier SupAgro)<br>Director: Jérôme Molénat, <a href="mailto:jerome.molenat@supagro.inra.fr">jerome.molenat@supagro.inra.fr</a><br>Contacts: Jérôme Molénat, <a href="mailto:jerome.molenat@supagro.inra.fr">jerome.molenat@supagro.inra.fr</a> & Olivier Grunberger, <a href="mailto:olivier.grunberger@ird.fr">olivier.grunberger@ird.fr</a><br><a href="http://www.umr-lisah.fr">www.umr-lisah.fr</a>   | 20   |   | • |   |   |   |
| <b>UMR MISTEA - Mathematics, Informatics and Statistics for Environment and Agronomy</b><br>(INRA/Montpellier SupAgro)<br>Director: Pascal Neveu, <a href="mailto:pascal.neveu@supagro.inra.fr">pascal.neveu@supagro.inra.fr</a><br>Contact: Bénédicte Fontez, <a href="mailto:benedicte.fontez@supagro.fr">benedicte.fontez@supagro.fr</a><br><a href="http://www6.montpellier.inra.fr/mistea">www6.montpellier.inra.fr/mistea</a>   | 52   |   |   |   |   | • |
| <b>UMR MOISA - Markets, Organizations, Institutions and Stakeholders Strategies</b><br>(CIRAD/INRA/Montpellier SupAgro/CIHEAM-IAMM)<br>Director: Paule Moustier, <a href="mailto:paule.moustier@cirad.fr">paule.moustier@cirad.fr</a><br>Contact: Étienne Montaigne, <a href="mailto:etienne.montaigne@supagro.fr">etienne.montaigne@supagro.fr</a><br><a href="http://umr-moisa.cirad.fr">http://umr-moisa.cirad.fr</a>  | 42   |   |   |   | • |   |
| <b>UMR Physiology and Experimental Medicine: Heart – Muscles</b><br>(UM, INSERM, CNRS)<br>Director: Jacques Mercier<br>Contact: Ariane Sultan, <a href="mailto:a-sultan@chu-montpellier.fr">a-sultan@chu-montpellier.fr</a><br><a href="http://u1046.edu.umontpellier.fr">http://u1046.edu.umontpellier.fr</a>  | 30   |   |   | • |   |   |
| <b>UMR SPO - Sciences for Enology</b><br>(INRA/Montpellier SupAgro/UM)<br>Director and Contact: Jean-Marie Sablayrolles, <a href="mailto:sablayro@supagro.inra.fr">sablayro@supagro.inra.fr</a><br><a href="http://www6.montpellier.inra.fr/spo">www6.montpellier.inra.fr/spo</a>   | 30   | • |   | • |   | • |
| <b>UMR SYSTEM - Tropical and Mediterranean Cropping System Functioning and Management</b><br>(CIRAD/INRA/Montpellier SupAgro/CIHEAM-IAMM)<br>Director: Christian Gary, <a href="mailto:christian.gary@supagro.inra.fr">christian.gary@supagro.inra.fr</a><br>Contact: Raphaël Métral, <a href="mailto:raphael.metral@supagro.fr">raphael.metral@supagro.fr</a><br><a href="http://umr-system.cirad.fr">http://umr-system.cirad.fr</a>   | 24   |   | • |   |   |   |
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| <b>Domaine de Vassal Experimental Unit</b><br>(INRA)<br>Director: Hernán Ojeda, <a href="mailto:ojeda@supagro.inra.fr">ojeda@supagro.inra.fr</a><br>Contact: Cécile Marchal, <a href="mailto:cecile.marchal@supagro.inra.fr">cecile.marchal@supagro.inra.fr</a><br><a href="http://www.l.montpellier.inra.fr/vassal">www.l.montpellier.inra.fr/vassal</a>   | 17   | • |   |   |   |   |
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# VINE CULTIVAR DIVERSITY

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# Analysis of grape genetic diversity and genome functioning

- I**n an ever-changing world, viticulture is facing many challenges:
- climate change, with rising temperatures and/or reduced rainfall, which have a direct impact on wine quality
  - changing consumer tastes, requiring modifications in the wine product supply
  - growing social concern on environmental issues, leading to marked reductions in pesticide use
  - the need for viticulture and wine product diversification, especially to enhance the competitive edge on global markets.

Highly diversified genetic resources are essential to address these challenges. In this respect, the Agropolis International scientific community hosts the largest grapevine genetic resource collection in the world (*Domaine de Vassal*). With 7 800 accessions, this unique treasure is preserved, characterized and may be disseminated to the entire scientific community and the vitiviculture sector.

A better understanding of grapevine diversity and genome functioning is also essential. Grapevine is the fourth plant species whose genome was unravelled. A homozygous variety was first sequenced by a Franco-Italian consortium, with the contribution of research teams of the Montpellier scientific community. The highly heterozygous Pinot noir variety was then sequenced by an Italian team\*\*.

Having the full sequence of bases that make up almost the entire grapevine genome led—via automated analysis—to the identification and positioning of most grapevine genes. Major advances have been achieved using this incredible tool, thus enhancing insight into certain traits of agricultural interest, such as grape skin colour.

Gaining complete knowledge of all grapevine genes, genome diversity and functioning is nevertheless still a medium-term objective. Teams of the Montpellier scientific community focused on viticulture and wine are thus conducting studies to enhance the overall understanding of:

- grapevine genetic diversity, especially for adaptation and quality traits, which requires access to high-throughput phenotyping platforms
- the evolution of the main grapevine species cultivated worldwide (*Vitis vinifera*), from its domestication until present, especially through numerous natural or controlled crosses that have led to current vine varieties. Archaeobotanical studies are also carried out to shed light on the earliest stages

- relationships between *Vitis vinifera* and different related species of the *Vitis* genus bearing favourable genes, such as genes of resistance or tolerance to certain pests, but which are also responsible for major defects, particularly regarding organoleptic features.

This research will shed light on the history of grapevine diversity from the origin of viticulture to today's varieties, but will also reveal ways to make better use of genetic resources in breeding programmes.

Moreover, the identification of grapevine genome zones, or even genes, involved in controlling crop yield and quality traits will help to better orient potential crosses to create tomorrow's varieties, while helping breeders accelerate vine breeding schemes so as to be more readily responsive to professional requests.

Finally, a better understanding of the biosynthesis pathways of the main primary and secondary compounds of grapes and signalling pathways could explain the effects of cropping practices on grapevine health and wine quality, while revealing the impacts of climate change and different biotic and abiotic stresses with regard to gene expression and metabolic pathway regulation.

This chapter presents the research and technology units of the Agropolis International community involved in these topics. It also presents the *Domaine de Vassal* grapevine repository and the phenotyping platform whose research is focused on the drought response, while showcasing several studies that are currently under way in these units.

**Patrice This (UMR AGAP)**

\* Jaillon *et al.*, 2007  
\*\* Velasco *et al.*, 2007

# Analysis of grape genetic diversity and genome functioning

## Grapevine breeding – from genetic diversity to the production of disease-resistant grapevine varieties adapted to changing environmental conditions

| Main teams  |
|---|
| <p><b>UMRAGAP</b><br/> <b>Genetic Improvement and Adaptation of Mediterranean and Tropical Plants</b><br/>           (CIRAD/INRA/Montpellier SupAgro)<br/>           250 scientists, with 14 involved in the topic<br/>           (Diversity, Adaptation and Breeding of Grapevine research team)</p> |
| <p><b>UMR B&amp;PMP</b><br/> <b>Biochemistry and Plant Molecular Physiology</b><br/>           (INRA/CNRS/Montpellier SupAgro/UM)<br/>           80 scientists, with 8 involved in the topic</p>  |
| <p><b>UMR ISEM</b><br/> <b>Institute of Evolutionary Sciences of Montpellier</b><br/>           (UM/CNRS/EPHE/IRD)<br/>           166 scientists, with 8 involved in the topic</p>  |
| <p><b>UMT Géno-Vigne®</b><br/> <b>Development of vine genetic resources in France</b><br/>           (IFV/INRA/Montpellier SupAgro)<br/>           23 scientists</p>  |
| <p><b>Domaine de Vassal Experimental Unit</b><br/>           (INRA)<br/>           8 engineers and technicians</p>  |
| Other teams focused on this topic   |
| <p><b>UMR LEPSE</b><br/> <b>Ecophysiology of Plants Under Environmental Stress</b><br/>           (INRA/Montpellier SupAgro)<br/>           15 scientists, with 5 involved in the topic</p>   |
| <p><b>UMR SPO</b><br/> <b>Sciences for Enology</b><br/>           (INRA/Montpellier SupAgro/UM)<br/>           45 scientists</p>  |
| <p><b>Domaine du Chapitre Experimental Unit</b><br/>           (Montpellier SupAgro/INRA)<br/>           7 engineers and technicians</p>  |

The adaptation of viticulture is essential considering its high environmental impact due to pesticide use, the intimate link with human societies through the *terroir* concept, the frequent location of vineyards around cities and the potential risk of climate change impacts on wine quality. A medium-term solution is the dissemination of new disease-resistant grapevine varieties that are better adapted to changing environmental conditions, while maintaining a high level of quality.

In this context, the *Diversity, Adaptation and Breeding of Grapevine (DAAV) team of the joint research unit Genetic Improvement and Adaptation of Mediterranean and Tropical Plants (UMR AGAP – CIRAD, INRA, Montpellier SupAgro)* aims to breed more disease resistant grapevine varieties that are better adapted to climate change while being of high quality. The unit focuses on three lines of research:

- studies on the diversity and evolution of grapevine and related species
- identification of the genetic and molecular basis of traits of interest and adaptation
- integration of this information for trait prediction and breeding of innovative varieties.

This research is enhanced by knowledge from various disciplines, including ampelography, population genetics, quantitative genetics, physiology and phytopathology, as well as methodological expertise in areas such as molecular biology, statistical modelling and algorithmics. To ensure targeted research, the research unit formed the joint technology unit (UMT) *Géno-Vigne®* (see p. 14) in partnership with the French Institute for Vine and Wine (IFV), thus enabling interaction with professional stakeholders in the sector.

The DAAV team is actively participating in managing the world's largest grapevine genetic resources collection at *Domaine de Vassal* (see p. 17) and has various technical and equipment resources (experimental plots, greenhouses, growth rooms). It also masters the dwarf grapevine production technique. The team has privileged access to a high-throughput genotyping platform and bioinformatics servers of the UMR AGAP South Green<sup>1</sup> platform and of the *Génomique Info* research unit (URGI, INRA Versailles). Some of the generated data are available online via SNIPlay<sup>2</sup>, VitPhe<sup>3</sup> and GnpIS.

1. The South Green platform was created to provide access to innovative methods and bioinformatics resources devoted to genomics and breeding of high yielding and high quality plants: [www.southgreen.fr](http://www.southgreen.fr)  
 2. SNIPlay: an SNP polymorphism data analysis and processing web application: <http://sniplay.cirad.fr>  
 3. VitPhe: an information system devoted to archiving, consultation and processing of experimental data from different projects and collected via different platforms (field, greenhouse, laboratory) : <http://bioweb.supagro.inra.fr/vitphe/public>

## Gaining insight into the history of grapevine varieties through DNA analysis

Molecular markers have been highly effective in studies on grapevine varieties, especially in the 1990s with the use of microsatellite markers, or simple sequence repeats (SSRs). These molecular tools have generated knowledge on three topics related to the history of grapevine varieties, i.e. their identification, genealogy, and the geographical structure of their diversity.

Varietal identification has benefitted substantially from the availability of molecular markers to back conventional ampelographic techniques. Many local, national and international studies have led to the confirmation or discovery of synonymous and homonymous varietal names, thus boosting insight into current and past ranges of certain 'traveller' grapevine varieties. These synonyms are now pooled in several online open access databases.

Genealogical studies began in 1993. Since then, several studies have confirmed or refuted hybridization data supplied by breeders, but more importantly they have revealed the pedigree of much older traditional varieties. This is how the parents of famous varieties—Chardonnay, Merlot, Syrah, etc.—were revealed. These results highlighted certain major parents in the past but which are no longer found in modern day vineyards (Gouais blanc, Magdeleine noire des Charentes, Mondeuse blanche, etc.).

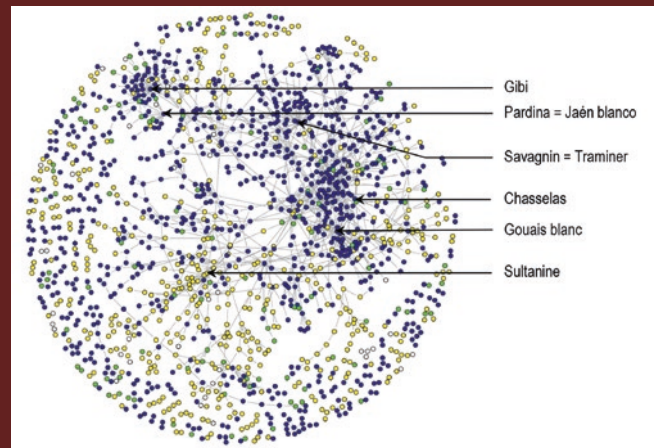
Diversity studies conducted at local, national or international scales have clarified the geographical origin of grapevine varieties beyond their direct genealogical origin. They led to the proposal of several diversity groups, some of which had not been suspected on the basis

of comparative morphological studies. The positioning of varieties in these diversity groups at different scales has clarified their possible geographical origins and historical pathways.

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▲ Network representing half-kinship relationships revealed in 2344 grapevine varieties in the Domaine de Vassal collection based on 20 microsatellite markers

Wine grape varieties are shown in blue, table grape varieties in yellow, and dual-purpose varieties in green, while black lines symbolize kinship.

© T. Lacombe, J.-M. Boursiquot, V. Laucou, M. Di Vecchi-Stara, J.-P. Peros, P. This

◀ A microvine plant (dwarf grapevine) with inflorescences at different development stages along the main stem

© L. Torregrosa/UMR AGAP, DAAV research team.

## Identification of the genetic bases of grapevine quality and adaptation

With the aim of identifying genomic regions and if possible genes involved in traits of interest, UMR AGAP conducts research in different populations to find statistical associations between genotypic variation of many markers distributed throughout the genome (DNA polymorphism) and phenotypic variation in traits measured on plants. These populations are derived from isolated or interconnected crosses (with common parents, e.g. in a diallel design), thus enabling comparison of results in different genetic backgrounds. The research unit also uses samples of unrelated varieties to more quickly and thoroughly investigate the available variability (association genetics). Plants are grown in the field or in pots to facilitate studies on the genetic bases of adaptation to water and heat stresses. In particular, studying a short-cycle dwarf progeny (microvines, see photo) allowed the entire population to be grown in a growth chamber under two different temperature regimes. New genomic regions involved in variations in berry weight and acid concentration over a broad temperature range were thus found. As many genes are present in these regions, screening based on the expression and variability profiles of these genes is thus necessary. When a gene is found to be a very likely candidate to explain the trait variability, functional genomics can be used to try to validate its effects on the trait.

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## Phenotyping platforms for automated analysis of drought tolerance in large plant populations

▲ *LEPSE phenotyping platform* © T. Simonneau

The Montpellier Plant Phenotyping Platforms developed by LEPSE (see p. 22) enable comparison of hundreds of grapevine genotypes grown in plant pots under drought conditions. This is one of the few facilities of this type in the world that features robotic control of soil drying for individual plants (up to 1680) set on platforms in a greenhouse. Individual plant growth and transpiration are automatically analysed by weighing of pots individually and by image analysis.

From 2012 to 2014, three experiments were conducted on a cross between two emblematic grapevine varieties in the South of France, i.e. Syrah and Grenache. The results obtained in collaborations with UMR AGAP highlighted many genomic regions involved in growth maintenance or in water conservation by plants under drought conditions. These findings could lead to the identification of grapevine varieties best adapted to current or future climate scenarios or to marker-assisted selection of new varieties.

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## Flavonoid biosynthesis in grapevine

Flavonoids are secondary metabolites essential for the quality of plant-based foods and beneficial for health. They are used for industrial applications, especially for their pigmentation, antioxidant and nutritional properties.

Major flavonoids in grapes are:

- anthocyanins—pigmentation molecules in grapevine varieties and red wine
- condensed tannins—involved in astringency and colour stabilization.

The main stages of flavonoid biosynthesis in grapes, and more generally in plants, are now known, but other steps are still relatively undocumented. One of the aims of the Biosynthesis and Composition in Polyphenols and Polysaccharides group of UMR SPO (see p. 30) is to identify:

- molecular mechanisms involved in certain final phases of flavonoid biosynthesis—especially methylation, acylation and polymerization, which modify the properties of these molecules
- flavonoid transport and storage processes within cells
- factors controlling their content and composition in grapes.

New genes are being sought by the following combined approaches:

- metabolomic: analysis of the flavonoid composition in cultivar tissues at different development stages
- transcriptomic: measurement of variations in gene expression between samples having different flavonoid contents
- genetic (with UMR AGAP): identification of genome regions controlling the flavonoid composition.

Several new genes have thus been identified. Characterization of these genes revealed their role in the regulation of flavonoid biosynthesis pathways, methylation and anthocyanin transport or tannin acylation.

Understanding these mechanisms could help gain further insight into flavonoid compound synthesis by plants according to environmental variations, and especially in relation to climate change (temperature, light, drought). The genes could also serve as markers in future breeding programmes.

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### ▲ Characterization of an anthocyanin methylation gene

From left to right:

1. Leaf extract without anthocyanins.

2. Leaf extract containing anthocyanins.

3. Leaf extract containing anthocyanins methylated through the activity of the studied gene (anthocyanin methylation intensifies their colour).

© A. Ageorges/UMR SPO-INRA

## Maintaining wine acidity by controlling potassium accumulation in grape berries

The joint research unit *Biochemistry and Plant Molecular Physiology* (UMR B&PMP – INRA, CNRS, Montpellier SupAgro, UM)

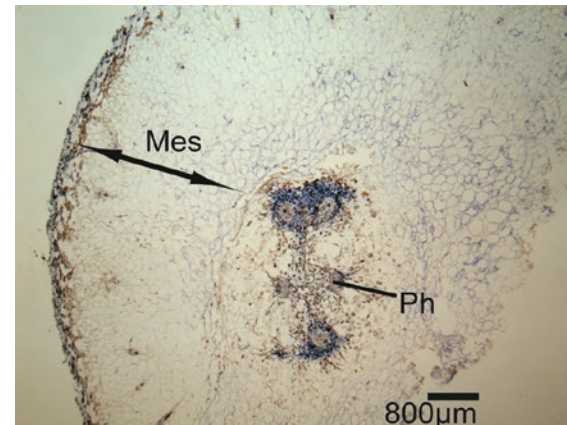
studies mechanisms that govern the hydromineral status of plants under different abiotic conditions by integrating research based on studies carried out in disciplines such as biochemistry, molecular and cell biology, physiology, biophysics and genetics. The unit is recognized worldwide for studies on plant cell transport activities (membrane channels and transporters) that are mainly focused on the *Arabidopsis* plant model. The KaliPHruit team of UMR B&PMP uses knowledge acquired on K<sup>+</sup> transport in the plant model to analyse the accumulation of this ion in grape berries and its impact on fruit acidity.

In grapevine, grape potassium contents have been constantly increasing over the last 20 years in relation to climate change. However,

when the grape K<sup>+</sup> concentration becomes excessive, this ion combines with tartaric acid—a major organic acid in grapes—to form highly insoluble potassium bitartrate which precipitates. There is a subsequent increase in the malate/tartrate ratio and pH in grapes, and hence alkalization of the must. This phenomenon substantially alters the grape and must quality because the acidity releases aroma during vinification. The wines obtained then have low organoleptic qualities and a low aging potential. Gaining greater insight into the mechanisms involved in K<sup>+</sup> accumulation in grapes during their development and under abiotic stress should ultimately help identify original and relevant markers that could be used by geneticists in breeding programmes.

UMR B&PMP has all the scientific potential required for analysing physiological and genetic mechanisms involved in increased K<sup>+</sup> accumulation in grapes and consequences in the decline of fruit acidity. To enhance the effectiveness of this study, the unit has established

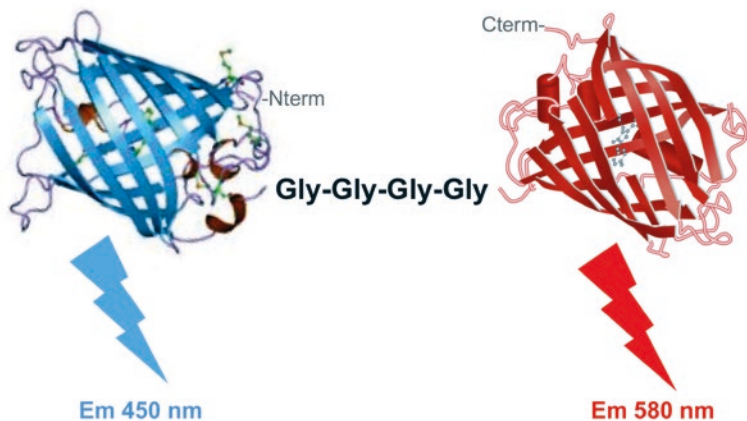
close collaborations with the ETAP team of UMR LEPSE (*see p. 22*), which has facilities for growing this species under carefully controlled conditions, and with the DAAV team of UMR AGAP (*see p. 10*), whose mission is to contribute to the creation of new grapevine varieties that meet sustainable viticulture challenges.



▲ Location of a K<sup>+</sup> channel by in situ hybridization in grape mesocarp (pulp cells)

Mes: mesocarp (grape pulp), Ph: phloem

© Isabelle Gaillard/BPMP and Teresa Cuéllar/CIRAD



▲ Ratiometric probe formed by tandem fusion of two low pK fluorescent proteins.

This probe is effective for pH measurement in grape vacuoles during ripening.

© N. Paris/B&PMP

Current probes have a pK of around 6, so they cannot be used for measuring vacuole pH, especially in grapes since the pH may be under 3 in some varieties. The KalipHruit team of UMR B&PMP has thus developed a new generation of probes based on tandem fusion of low-pK fluorescent proteins, i.e. a blue fluorescent protein fused by a few glycine residues to a red fluorescent protein. Fluorescence emissions of the two proteins are recorded and the pH is deduced from the fluorescence ratio, which is precalibrated *in vitro* with a range of buffers.

The first two probes obtained were expressed in a bacterial system and analysed by spectrometry. They will subsequently be fused to addressing signals so as to enable their accumulation in vacuoles and their expression in grapes. The pH will be measured via confocal microscopy and by calculating the fluorescence ratio of the two proteins.

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## Ratiometric fluorescent probes for noninvasive measurement of acidic pH in grape berries

The acidity of grapes at harvest is an essential factor for obtaining good wine. Low-acidity grapes produce relatively sweet and quite tannic alcoholic wines because it is the acidity—also called ‘freshness’ in oenology—that releases aromas and flavours from grapes. Moreover, global warming increases the pH in grape vacuole cells.

As part of the ANR-funded SweetKaliGrape project (2015-2018), grape acidity during ripening will be analysed and correlated with potassium and sugar accumulation processes. Ratiometric fluorescent probes, expressed in grapes via genetic engineering, will make it possible to noninvasively measure—contrary to proton microelectrodes—the pH by imaging at cellular and subcellular scales (250 nm optimum resolution).

## Effective use of grapevine genetic resources in France

The joint technology unit *Géno-Vigne*<sup>®</sup> (UMT *Géno-Vigne*<sup>®</sup> – INRA, Montpellier SupAgro, IFV) was certified by the Directorate General of Education and Research of the French Ministry of Agriculture in 2008. Joint technology units (UMT) provide an interface between research and development and enable joint management of nationally-oriented research and development programmes. They associate a qualified technical institute and a public research institute or a higher education establishment in joint projects. The UMT *Géno-Vigne*<sup>®</sup> project thus associates the IFV National Plant Material Pole, UMR AGAP, *Domaine de Vassal* and *Domaine du Chapitre*. The joint research units (UMR) Ecophysiology and Grape Functional Genomics (INRA Bordeaux) and Grapevine Health and Wine Quality (INRA Colmar), the experimental unit (UE) Pech Rouge and UMT QUALINNOV are now associated with *Géno-Vigne*<sup>®</sup>.

UMT *Géno-Vigne*<sup>®</sup> aims to streamline the management, conservation and development of grapevine genetic resources in France in favour of the wine industry. It is geared

towards varietal innovation, from characterizing grapevine genetic resources, technology development and transfer, conducting trials on innovative plant material, to obtaining new varieties that are registered in the national catalogue.

The primary goals are:

- 1 To enhance genetic resource management and develop alternative conservation methods through an integrated action plan for grapevine genetic resource management at the national level (UE *Domaine de Vassal*, IFV and network partners), ISO 9001/2008 certification (which specifies the quality management system requirements), sanitary characterization and sanitation of genetic resources and marker-assisted identification (varietal identification and clonal polymorphism).
- 2 To improve sanitary and phenotypic characterization of genetic resources and make effective use of available genetic resources (varieties and clones): genetic resource phenotyping and development of high-throughput phenotyping tools, testing of more effective genotyping approaches, assessment of methods for identifying the genetic basis of polymorphism.

- 3 To propose high performance plant material to address the need to reduce pesticide inputs while coping with climate change: development of elite parents with oligogenic resistance\* to cryptogamic grapevine diseases (downy mildew, powdery mildew) and pre-breeding populations\*\*, definition of ideotypes\*\*\* for the sector, breeding and molecular marker-assisted selection so as to link regional typicity and disease resistance, assessment of field-selected genotypes, development of new clones, old or foreign varieties, set up of multisite experiments, innovation and innovative management strategies.
- 4 To facilitate access to information and knowledge by developing tools to help in identifying grapevine varieties and by supporting training initiatives.

The unit benefits from its members' infrastructures and resources (experimental vineyards, laboratories, collections, documentation centre, greenhouses, vinification building, equipment, etc.).

\* Resistance determined by a small number of genes.

\*\* Populations intended for later use in breeding programmes.

\*\*\* New varieties selected for their capacity to make optimal use of a given environment and fulfilling approved specifications.

▼ View of the *Domaine de l'Espiguette* © IFV





▲ Breeder removing all flowers from a grapevine flower cluster © T. Flutre

## Breeding downy and powdery mildew resistant grapevine varieties

One current major challenge in viticulture is to ensure environment-friendly production in a climate change setting. Grapevine breeding can help address this challenge based on the professional expectations and available scientific knowledge. Discussions are under way with professional wine producers in different wine-growing areas to add criteria specific to their region to these global challenges. This joint 'ideotype definition' step helps in choosing parent material and breeding criteria prior to carrying out crosses. Each grape seed obtained will then generate a single plant, but only a few selected ones will ultimately match the defined ideotypes.

Candidate varieties are selected in three stages, with a 5% selection rate per stage. The first stage includes two steps —selection using genetic markers (DNA sequences for identifying individuals bearing certain sought-after traits) and greenhouse selection (3-4 years, to obtain material for

propagation). The second stage includes the planting of 5-10 vine plants in the field to be monitored with regard to viticultural practices and to carry out microvinification tests (~6 years). The last stage involves selection tests, with 90 vine plants and controls at two sites, to collect data necessary for variety cataloguing (~6 years).

Different grapevine breeding programmes are currently under way in partnership with UMR Grapevine Health and Wine Quality (INRA Colmar) to obtain downy and powdery mildew resistant varieties with the aim of reducing pesticide treatments for diverse production types (Champagne, Cognac, Bordeaux, rosé wine, table grapes). Moreover, studies are being carried out by UMT *Géno-Vigne*®, along with UMR AGAP, to reduce the breeding time by using genetic markers spanning the entire genome (i.e. 'genomic selection') to replace stage 2.

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## Origins and historical biogeography of viticulture

The joint research unit **Institute of Evolutionary Sciences of Montpellier (UMR ISEM – UM, CNRS, EPHE, IRD)** conducts research on the origins and dynamics of biodiversity and the conditions and mechanisms involved in its evolution. This research concerns both current and past biodiversity and includes a broad range of organisms and environments. A combination of field, experimental and theoretical approaches are implemented.

The Biodiversity Dynamics and Human Ecology team at ISEM

focuses on biological, ecological and historical aspects of interactions between organisms, communities of organisms (mainly plants), environmental parameters (particularly soil and climate) and human activities.

The team conducts research on the domestication and biogeographical history of grapevine diversity from the origin of viticulture based on bioarcheological archives and on interactions between archeobotanical tools, morphometry and genetics. As part of the Observatory for Science of the Universe–Observatory for

Research on the Mediterranean Environment (OSU-OREME), for several years the team has been monitoring the demographic, biological, ecological and sanitary status of wild grapevine populations in Languedoc-Roussillon (France).

This research is supported by federative research bodies (OSU-OREME) and funding from national (French National Research Agency, [ANR], development aid, etc.) and international programmes, by platforms (archeobiology, morphometry, etc.) and national and international collaborations.

## Archeobiology of grapevine Roman origins of the Languedoc wine-growing region

The combination of archaeology, archeobotany and morphometric methods can be used to investigate the palaeodiversity of cultivated grapevine, while also placing it in its chronological, ecological, biogeographical, technoeconomic and cultural context.

In recent years, preventive archaeology has revealed a high number of Gallo-Roman wineries, thus helping to gain further insight into the history and functioning of the first specialized viticulture in Languedoc region (France). Due to the presence of wells, these sites often deliver high quantities of perfectly preserved plant remains (wood, seeds, leaves and other remains), which is direct evidence of the environment and economy of these wineries. Grapevine is a pivotal element in these records.

Morphometric methods are applied to assess archaeological grape seeds and charcoal in order to characterize past diversity by direct comparison with reference models established through the analysis of current materials.

These studies, carried out by the Biodiversity Dynamics and Human Ecology team of ISEM, have revealed the high diversity of domestic grapevines grown in Roman wineries. They have shown that morphologically wild grapevines were systematically harvested alongside domestic types, which raises questions about the history of the domestication, ecology, geographical distribution, evolution and paleoagronomy of grapevine. The results of this research contribute to the themes and expositions of the *Jardin Antique Méditerranéen* (Balaruc-les-Bains, France)\*.

\* [www.thau-agglo.fr/vivre/la-culture/jardin-antique-mediterraneen](http://www.thau-agglo.fr/vivre/la-culture/jardin-antique-mediterraneen)

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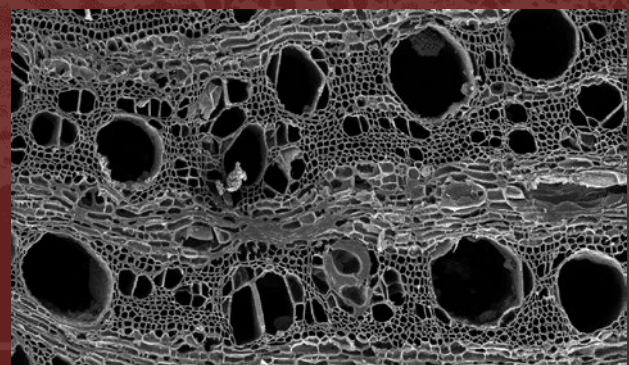


▲ Waterlogged grape (*Vitis vinifera*) seeds from a well at the Roman site of Lesse (2<sup>nd</sup>-3<sup>rd</sup> c. AD) at Sauvian (Hérault, France) (INRAP excavations, study I. Figueiral).  
© S. Ivorra/CNRS–ISEM

► Cross-section of grapevine (*Vitis vinifera*) charcoal from a well at the Roman site of Mont Ferrier (1<sup>st</sup> c. AD) at Tourbes (Hérault, France) (INRAP excavations, study I. Figueiral)  
© S. Ivorra/CNRS–ISEM



▲ Waterlogged grapevine (*Vitis vinifera*) twigs from a well at the Roman site of Terrasses de Montfau at Magalas (Hérault, France) (INRAP excavations, study I. Figueiral) © S. Ivorra/CNRS–ISEM







▲ An ampelographic collection plot at the Domaine de Vassal © T. Lacombe

## Vassal-Montpellier Grapevine Biological Resources Center

The ampelographic collection of the experimental unit (UE) of *Domaine de Vassal* (INRA), located at Marseillan-Plage (Hérault, France), is devoted completely to the conservation, characterization and effective use of grapevine genetic resources.

This repository was founded in 1949 at the initiative of Jean Branais, who at the time was head of the Viticulture Chair at the *École Nationale d'Agriculture de Montpellier* (now Montpellier SupAgro). It was initially based on the highly diversified ampelographic collections started by Gustave Foëx as early as 1876 on the school site and gradually enlarged, especially by Louis Ravaz. After WWII, soilborne pest and disease problems, in addition to threats of urbanization, necessitated the transfer of this collection to a site with better sanitary conditions and long-term sustainability.

The Vassal site, on the sandy coastal belt separating the Thau lagoon and the Mediterranean Sea, was chosen because the sand was free of agents causing two serious grapevine diseases, i.e. the radicicolous form of phylloxera and the *Xiphinema index* nematode, vector of the grapevine fanleaf virus. Grapevine can thus be grown there without rootstock.

Over the past 140 years, this collection has been continuously enhanced by donations (old local collections, wine growers, nursery owners, non-professional enthusiasts, etc.) and through various collection surveys conducted in France with regional partners and abroad by scientists or research institutes. Paul Truel (Director, 1954-1985) was highly instrumental in the acquisition, description and accurate identification of many grapevine varieties. The repository currently hosts more than 7 800 grapevine accessions from 54 wine-producing countries, representing 2 700 grapevine varieties, 350 wild grapevine varieties, 1 100 interspecific hybrids, 400 rootstock varieties and 60 *Vitaceae* species. This is a unique grapevine collection in the world because of its richness and diversity.

Grapevines maintained in this repository undergo morphological, phenological, agronomic, technological, sanitary, genetic and bibliographical characterization. The aim of these studies is to identify the varieties and fully assess their potential for meeting the expectations of scientists, breeders, professionals in the wine production sector and the general public. This has given rise to a unique collection of documents, including varietal files (over 5 000), herbaria (14 000 files), a specialized library, a photo library (50 000 photos) and an accessible online electronic database.

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► *Mechanical weeding  
under grapevines to avoid  
herbicide applications*  
*Here barley is also sown in the  
interrows to control the vegetative  
vigour.* © Y. Bouisson



# Vineyard management, agricultural practices and impact reduction

**I**n a setting in which vineyard replanting is relatively slow and highly regulated, the adoption of new vineyard management strategies can be effective in addressing current socioeconomic and environmental challenges. Some crop management practices in use or under development can help mitigate the negative impacts of climate change or pest pressure on vine production. For instance, grape bunch heating can be reduced by using tailored trellising methods. The biotic environment may be modified by introducing beneficial insects to prey on grapevine pest insects thereby reducing pesticide use. Other strategic management options implemented on a wine-growing region scale are effective in controlling soil erosion and pollutant flows.

With this outlook of adjusting vineyard and vineyard landscape management strategies to address a spectrum of agroecological issues, several research units of the Agropolis scientific community analyse grapevine functioning and interactions with the physical, physicochemical and biotic environment. The scale of this broad scope research ranges from individual plants, plots and farms to vineyard landscapes. The mechanisms that determine plant water consumption, plant cover evapotranspiration and, more broadly, water circulation in vineyard landscapes in relation to the soil moisture properties, are currently major scientific concerns. Production stability on a multiyear scale is also the focus of studies aimed at gaining further insight into the direct and indirect effects of years of exceptional climatic conditions with regard to both crop yield and quality. Moreover, biocontrol methods are being explored to meet national pesticide reduction objectives (Ecophyto Plan). This includes boosting knowledge on the behaviour of pests and beneficial organisms that are effective in vineyards, as well as investigating technological options such as improving spraying techniques and agricultural options in relation to tillage or growing cover crops that consume little or no pesticides. In addition, it is necessary to develop agroenvironmental assessment methods and tools (at the plot and landscape scale), innovative agricultural practices to control crop yields, pest regulation, and optimal use of soil water and nitrogen resources.

The research teams have developed several systems for long-term *in situ* observation of practices and environments (*Observatoire Méditerranéen de l'Environnement Rural et de l'Eau*), remote-sensing data collection (spatialization of vineyard evapotranspiration) and the analysis of specific agricultural practices in platforms (Low Input Vineyard Experimentation [LIVE]) and experimental estates (*Domaine du Chapitre*, UE Pech Rouge). All of these systems enable the collection of large datasets on agricultural practices, physiological conditions in vineyards and biophysical features of the plant environment (soil, surface and ground water; atmosphere, microfauna). Modelling is another scientific tool used to understand and predict vineyard functioning at different scales, from the plant (INNOVINE project), to the plot (FertilCrop project) and the overall vineyard landscape (Phyt'Eau Mod project). The models also provide a basis for the development of support tools (Phyt'Eau Mod and PURE projects) aimed at assessing vineyard management from agricultural and environmental standpoints. The overall approach—combining experimentation, observation and modelling—is especially valuable for assessing interactions between different components of complex vineyard systems in their biotic and abiotic environment. Several research projects presented in this chapter are carried out in partnership with interprofessional viticulture stakeholders, farm advisory firms, agricultural input manufacturers and local authorities.

**Jérôme Molénat (UMR LISAH)  
& Thierry Simonneau (UMR LEPSE)**

# Vineyard management, agricultural practices and impact reduction

## Engineering of cultivated and developed landscapes for sustainable water and soil management

|   |
|---|
| <p><b>Main teams</b></p> <p><b>UMR LEPSE</b><br/>Ecophysiology of Plants Under Environmental Stress<br/>(INRA/Montpellier SupAgro)<br/>15 scientists, with 5 involved in the topic</p>              |
| <p><b>UMR LISAH</b><br/>Laboratory on Interactions between Soil, Agrosystems and Hydrosystems<br/>(INRA/Montpellier SupAgro)<br/>23 scientists, with 16 involved in the topic</p>                   |
| <p><b>UMR SYSTEM</b><br/>Tropical and Mediterranean Cropping System Functioning and Management<br/>(CIRAD/INRA/Montpellier SupAgro/CIHEAM-IAMM)<br/>20 scientists, with 7 involved in the topic</p> |
| <p><b>UMT ECOTECH-VITI</b><br/>(IFV/IRSTEA/Montpellier SupAgro/IHEV)<br/>6 scientists</p>   |
| <p><b>Domaine du Chapitre Experimental Unit</b><br/>(Montpellier SupAgro/INRA)<br/>7 engineers and technicians</p>  |
| <p><b>Other teams focused on this topic</b></p>   |
| <p><b>Pech Rouge Experimental Unit</b><br/>(INRA)<br/>6 scientists, 30 engineers and technicians</p>  |
| <p><b>UMR Innovation</b><br/>Innovation and Development in Agriculture and the Agrifoods Sector<br/>(INRA/Montpellier SupAgro/CIRAD)<br/>50 scientists, with 4 involved in the topic</p>            |
| <p><b>UMR CBGP</b><br/>Centre for Biology and Management of Populations<br/>(INRA/CIRAD/Montpellier SupAgro)<br/>52 scientists, with 2 involved in the topic</p>                                    |

The scientific aims of the **Laboratory on Interactions between Soil, Agrosystems and Hydrosystems (UMR LISAH – INRA, IRD, Montpellier SupAgro)** are to:

- develop knowledge on mass transfers and pollutant dynamics in soils and catchments relative to their natural or anthropogenic spatiotemporal organization
- develop tools for the assessment and prevention of risks caused by human activities in cultivated environments affecting hydrological regimes and the evolution of water and soil resources
- contribute to developing new sustainable cultivated landscape management methods.

The laboratory also trains students on concepts and tools concerning the analysis and modelling of the spatial organization and hydrology of cultivated environments.

Vineyard agrosystems are a specific focus of LISAH research because of the environmental management issues (water, soil) involved, and the fact that these agrosystems can serve to cope with pressing scientific questions, concerning:

- relationships between agricultural practices—especially regarding soil maintenance (green cover, chemical or mechanical weeding, etc.)—and the genesis of runoff and infiltration
- evapotranspiration functioning of heterogeneous perennial plant covers at different scales, from the agricultural plot to the landscape
- factors determining soil erosion
- spatialization of natural (soil) and anthropogenic (field patterns, agricultural practices, irrigation systems) properties of cultivated landscapes.

This research aims to contribute to the engineering of cultivated landscapes in order to enhance sustainable water and soil resource management. In a global change setting (climate variations, new agricultural and food needs, etc.), this involves proposing cultivated landscape management strategies by streamlining the spatial organization of agricultural activities (land use, crop rotations, soil maintenance practices, crop treatments, etc.), as well as irrigation schemes (ditch networks, hillside catchments, embankments, etc.).

LISAH manages the *Observatoire Méditerranéen de l'Environnement Rural et de l'Eau* (OMERE, see next page), which consists of two catchments, including the Roujan viticulture catchment in Hérault department (France). Moreover, the laboratory is developing the OpenFLUID software platform for simulation of fluxes in landscapes. LISAH develops partnerships with national and international scientific teams, especially in North Africa (Tunisia, Morocco), as well as with public (French National Agency for Water and Aquatic Environments, French Agency for Food, Environmental and Occupational Health and Safety, etc.) and private (consulting firms) socioeconomic stakeholders.



▲ An overview of the Roujan experimental catchment © C. Slagmulder/INRA



▲ System for measuring water and rainfall flows and quality at the outlet of the site

© O. Huttel/INRA

OMERE is an environmental research observatory devoted to gaining insight into and assessing the effects of climate change and of changes in agricultural practices and land use on water and soil dynamics at the Mediterranean agricultural landscape scale. The observatory specifically aims to:

- 1 understand the impact of agricultural activities on mass fluxes in Mediterranean elementary catchments (hydrological regimes and balances, water resource allocation, erosion dynamics, water quality variations)
- 2 assess the intensities and rates of quantitative and qualitative changes in water and soil resources according to land-use changes
- 3 support the development of approaches for modelling fluxes in cultivated environments by closely associating field observations and modelling data
- 4 provide scientific bases, references and assessment tools for agroenvironmental engineering of cultivated landscapes.

The observatory consists of two sites—a catchment in Tunisia, monitored since 1994, and a viticulture catchment in Hérault department, France (Roujan municipality), monitored since 1992. In the latter catchment, relationships between the main soil maintenance practices in vineyards (green cover, mechanical tillage, chemical tillage) and the genesis of runoff and infiltration are studied, along with the factors that determine soil erosion in vineyard soils and of grapevine evapotranspiration as a function of the soil water status. The observatory also contributes to the study of soil spatialization, landscape features of hydrological interest (ditches, embankments, etc.) and agricultural practices.

The observatory includes systems for measuring hydrological, meteorological, hydrochemical and erosion factors from plot to catchment scales. Agronomic observations and measurements are also obtained. The observatory is co-managed by UMR LISAH and HydroSciences Montpellier, as well as by the *Institut National Agronomique de Tunis* and the Tunisian *Institut National de Recherche en Génie Rural, Eau et Forêts*.

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## Phyt'eau BV Mod project – assessment of pesticide pollution of water in vineyards

Grapevine cropping is a pesticide-intensive activity, accounting for around 15% of agricultural pesticide consumption in France whereas this crop represents less than 5% of the utilized agricultural area. Pesticide pollution of water in wine-growing regions is therefore often high and the cause of degradation of numerous water resources.

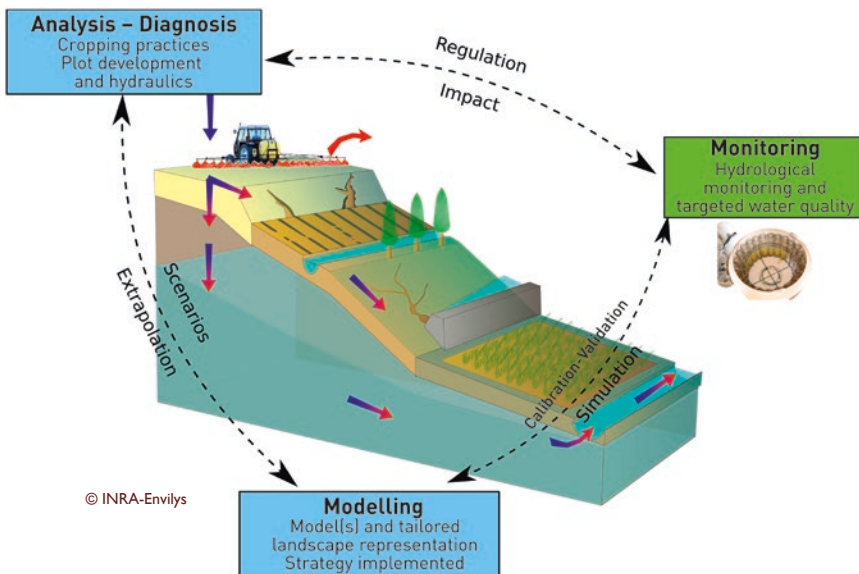
Based on experimental and modelling research carried out by UMR LISAH on water contamination by pesticides in viticulture catchments, the Phyt'eau BV Mod\* research and development project was carried out by the unit in partnership with the Envilys engineering consultant

firm and the Eurofins analytical laboratory. The aim was to develop an integrated modelling tool combined with field measurement instruments to assess pesticide treatment practices and their surface water resource contamination impacts. The tool was developed on the basis of the MHYDAS hydrological model and the OpenFLUID landscape simulation platform, which were both developed by LISAH researchers. The project was applied to environmentally assess viticulture catchments in Languedoc-Roussillon region (France) and resulted in a service offer called the *Observatoire des Pollutions diffuses* (nonpoint source pollution observatory), which was awarded the *Hydro Innovation* second prize at the HydroGaïa International Water Exhibition in 2011.

\* Integrated diagnostic and decision-support tool for nonpoint source pollution by crop protection products.

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▲ The grapevine plant preparation platform, located on the Montpellier SupAgro campus, where potted plants are conditioned according to experimental requirements.

LEPSE technicians prepare several thousands of pots yearly for phenotyping experiments, e.g. on the effects of nitrogen fertilization, growth, genetic variability in responses to water deficits, etc.  
© G. Bouteillier

## Grapevine tolerance to drought, high temperatures and low inputs

To address the negative impacts of climate change on crop production, the joint research unit **Ecophysiology of Plants Under Environmental Stress (UMR LEPSE – INRA, Montpellier SupAgro)** conducts research to find tolerant varieties and crop management strategies adapted to maintaining sufficient production under hot dry climatic conditions.

The Plant Transpiration Efficiency and Adaptation to Dry Climatic Conditions team focuses research on grapevine with the aim of enhancing vineyard tolerance to drought, high temperatures and, more recently, low inputs (especially nitrogen). Studies are conducted with geneticists to breed tolerant grapevine varieties, with agronomists to propose new crop management strategies, and with molecular biologists to identify physiological processes that could have a key role in tolerance to the studied constraints.

Plant tolerance to climatic constraints and input reductions is assessed in detail at the leaf scale through the analysis and modelling of growth, water consumption, water status and photosynthetic activity. At the whole plant scale, tools for the characterization and reconstruction of the spatial structure of grapevine are developed (by digitization, image analysis and modelling) for different varieties, as well as pruning and trellising systems. These tools can be used to assess the impacts of vine training options on the microclimate around the plants and on their growth and development. It is thus possible to classify management strategies and varieties according to their impacts on the light interception and water use efficiency (quantity of water necessary for a given yield), on fruit microclimate (sunlight exposure and temperature) and berry composition.

The experiments are carried out under controlled conditions (greenhouses and laboratory growth chambers) and in vineyards

(experimental unit plots or partner producers). The laboratory also develops unique phenotyping platforms (*see p.12*), which enable the comparison of high numbers of different varieties/rootstocks (up to 1 600 plants simultaneously) under controlled climate conditions.

These studies are supported by joint projects with local (UMR AGAP, SPO, SYSTEM and Innovation), national (UMR *Écophysiologie et Génomique Fonctionnelle de la Vigne*, Bordeaux) and foreign (University of the Balearic Islands and of Lisbon, Geisenheim Research Center [Germany], National Agricultural Technology Institute [Argentina]) partners. Research with UMR AGAP is at the forefront of genetic progress, while that with UMR SYSTEM is geared towards streamlining vineyard management.

## Mapping vineyard evapotranspiration on a regional scale



▲ *Evapotranspiration measurement device set up in the Roujan catchment*  
© L. Prévot/UMR LISAH

UMR LISAH developed a simple vineyard evapotranspiration mapping method based on satellite images. The study focused on the lower Peyne river valley, a tributary of the Hérault river, where vines are grown on over 70% of the area. Twelve ASTER images were acquired between July 2007 and October 2008. These surface temperature images (90 m spatial resolution) were converted into daily evapotranspiration maps using WDI\* and S-SEBI\*\* indices, which had yet to be used for vineyard mapping. Measurement devices were installed on seven vineyard plots representative of the soil-landscape variability in the Peyne river valley in order to validate these evapotranspiration maps. Direct evapotranspiration measurements—using the eddy covariance technique—were obtained on two of these plots.

Moreover, regular monitoring of soil moisture and groundwater levels enabled accurate daily evapotranspiration assessments on the seven plots via the HYDRUS-ID water flow, heat and solute transport model\*\*\*.

The satellite image-based evapotranspiration maps were successfully validated, with the S-SEBI index\*\* being slightly more precise (0.8 mm/day) than the WDI index\* (1.0 mm/day). Moreover, the evapotranspiration maps obtained had a temporally stable spatial structure, similar to that of the 1:25000 soil map. Besides using these evapotranspiration maps for estimating grapevine water needs, e.g. for irrigation, this work could be extended to encompass spatial management of viticulture practices (e.g. the green cover potential). The information generated could then potentially be used for mapping soil hydrodynamic properties.

\* WDI: water deficit index, Moran et al., 1994

\*\* S-SEBI: simplified surface energy balance index, Roerink et al., 2000

\*\*\* Simunek et al., 2005

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## Modelling to assess the performance of grapevine training systems

The comparison of pruning and training with regard to tall perennial plants like grapevines is problematic due to: (1) the high interannual climatic variability, and (2) the difficulty in gaining access to the systems where many different strategies would have to be studied (at least 50 pruning and trellising methods have been documented in vineyards). A 3D plant functioning modelling approach was thus implemented by LEPSE to simulate performances according to many potential pruning and trellising choices. The developed model predicts the microclimate of each leaf (especially the radiation it received and its temperature) and impacts on photosynthesis and transpiration (see figure 1). Several trellising methods can thus be classified on the basis of their transpiration efficiency (i.e. quantity of water necessary for a given growth (see figure 2)). This simulation approach was validated by comparing values simulated by the model with measurements obtained on whole plants in the vineyard within a chamber where the transpiration and net photosynthesis of the whole plant were recorded (see figure 3). This study involved a collaboration with the National Agricultural Technology Institute at Mendoza in Argentina (INTA) and is continuing with new applications geared towards water savings and mitigating the negative effects of global warming.

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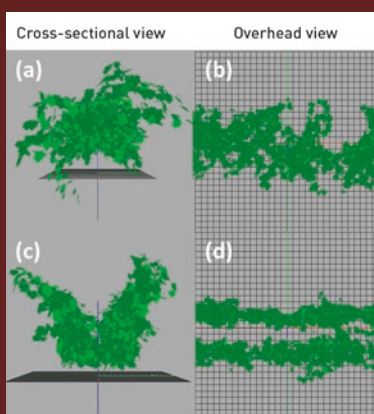
▲ *Fig. 3 Mobile greenhouse for grapevine climatological analysis*

INRA scientists prepare the mobile greenhouse for measuring the physiological responses of grapevines (transpiration, growth) to certain controlled climatological parameters ( $CO_2$ , temperature).

© psaila.net

► *Fig. 1 Examples of the reconstruction of 3D models of free cordon (a,b) and Lyre (c,d) types of vine training systems*

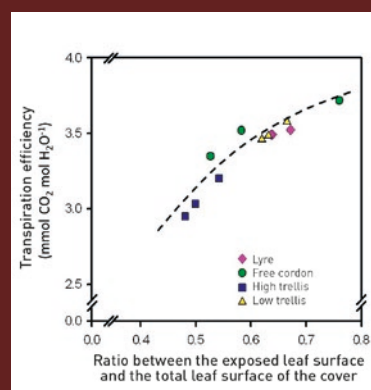
© INRA/LEPSE



► *Fig. 2 Relationship between transpiration efficiency (net assimilation/transpiration) simulated at the cover scale and the proportion of foliage exposed to direct sunlight for four vine training systems*

Each point corresponds to an individual plant placed in a virtual scene.

From Prieto et al., 2013



### Ecological intensification of viticulture

The joint research unit **Tropical and Mediterranean Cropping System Functioning and Management (UMR SYSTEM – CIRAD, INRA, Montpellier SupAgro, CIHEAM-IAMM)** conducts research on multispecies cropping systems. Agroforestry and viticulture in Mediterranean and tropical areas are the main models studied. The unit explores the hypothesis that the diversity of species grown in the same area and the control of their interactions promote ecological intensification. It generates knowledge and tools to assess and design cropping systems that combine economic performance and the production of environmental services.

Ecological intensification of viticulture involves identifying cropping systems that represent a good trade-off between the production and quality of grapevine products on the one hand, and low environmental and sanitary impacts

on the other. UMR SYSTEM focuses research especially on the leeway offered by soil maintenance without herbicide treatments and based on green cover (partial or total, sown or spontaneous), sometimes combined with targeted irrigation and fertilization. Through the soil water and nitrogen balance, green cover impacts crop yield build-up and grapevine quality, as well as the exposure of plants to fungal diseases resulting from their vegetative growth.

UMR SYSTEM develops indicators and modelling tools for preliminary investigation of trade-offs between yield management and pest control. Developing viticulture production methods that are less dependent on pesticides requires tools to assess the crop production potential under the prevailing conditions regarding soil water and nitrogen resources and crop losses due to uncontrolled pest infestations. The research unit is involved—in partnership with IFV—in the coordination of EcoViti, a regional and national network that pools six experimental platforms

devoted to innovative, participatively-designed viticulture systems with low pesticide inputs. This is carried out in the framework of the French Ecophyto plan, which requires a significant reduction (-50%) in the use of pesticides in agriculture.

UMR SYSTEM also studies—in networks of winegrower's plots—factors involved in the evolution of biological, environmental and technical components of cropping systems undergoing a transition to organic farming.

Since 2002, the unit has been managing the Low Input Vineyard Experimentation (LIVE) research platform at the *Domaine du Chapitre* (see p. 27). It supports different national and European projects (e.g. PURE and FertilCrop projects; see p. 64) and hosts a team of six researchers, engineers and teacher-researchers, and three technicians.

▼ Soil profile in a viticulture plot (Domaine du Chapitre) © UMR SYSTEM







▲ Ripe grapes (cv Mourvèdre) in a trial of a low-input viticulture system at the Domaine du Chapitre © Y. Bouisson/UMR SYSTEM

## Reducing pesticide use through integrated pest management in vineyards

The European PURE project\* (FP7, 2011-2015) brought together 24 partners from 10 countries to develop IPM strategies so as to reduce pesticide dependence in the main plant production sectors. The aim was to help these sectors comply with European regulations in order to reduce their impacts on human health and the environment, while continuing to quantitatively and qualitatively maintain a satisfactory level of food production.

UMR SYSTEM contributed to activities devoted to viticulture and especially to the assessment of low-input wine-growing systems. Two avenues were investigated: (1) the use of decision-support tools to reduce the number of pesticide treatments and dosages, and (2) the systematic use of biocontrol products.

The multicriteria DEXiPM analysis tool was adapted to grapevine to assess the sustainability of innovative IPM strategies that were developed and tested by the project partners. This tool divides the

environmental, economic and social dimensions of sustainability into criteria and sub-criteria so as to aggregate a set of assessment indicators by weighting in a 'decision tree'. These qualitative indicators were formulated to be more readily adopted in the field.

The results showed that the biocontrol strategy is more effective from an environmental standpoint, but is less so from an economic standpoint and the use of decision support tools offers the best trade-off between economic and environmental performance and acceptance by wine-growers.

\* The Innovative Crop Protection for Sustainable Agriculture project (FP7, the EU 7<sup>th</sup> framework programme)

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## Modelling crop losses due to grapevine pests and diseases

The DAMAGE key action of the Sustainable Management of Crop Health (SMaCH) metaprogramme of the National Institute for Agricultural Research (INRA) includes research projects on harvest loss due to pests and diseases in different crops (grapevine, coffee and fruit crops). UMR SYSTEM, in collaboration with the UMR Vine Health and Agroecology (SAVE, INRA Bordeaux), coordinates the project focused on grapevine.

At the *Domaine du Chapitre*, experimental data were collected over three crop seasons (2013-2015) on the dynamics of the main grapevine pests and diseases—mildew, powdery mildew, botrytis rot and grape berry moth—and on crop yields and components. Two viticulture systems of the EcoViti programme were thus tested in a cv Grenache vineyard plot, i.e. Innobio (prophylaxis by desuckering, leaf thinning, etc.) and IPM -50 (no toxic chemicals applied). A trial on the capacity of grapevine plants to offset early losses caused by diseases or pests at the beginning of the season was also conducted in Montpellier in parallel with tests on experimental plots in the Bordeaux region.

These data will be correlated with those acquired previously by UMR SAVE in the Bordeaux region and used to develop and configure a model to link viticulture production situations (climate and biotic stress level) with crop loss. This model should ultimately help prioritize problems associated with pests and diseases.

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## Reducing vineyard dependence on pesticides

The French Agriculture Ministry's Ecophyto plan aims to reduce pesticide use by 50% in France by 2025. The research and development carried out since 2013 by the joint technology unit (UMT) **ECHOTECH-VITI (IFV, IRSTEA, Montpellier SupAgro)** is thus aiming to develop sustainable viticulture systems by reducing vineyard dependence on pesticides while maintaining their competitiveness. Studies are focused on the following topics:

- development of decision-support tools for conventional and organic viticulture to optimize phytosanitary input use
- assessment of the agroenvironmental performance of spraying technologies to promote the purchase of efficient sprayers and the adoption of optimized practices
- contribution to the development and use of innovative technologies

(operational monitoring sensors, vegetation measurement probes, etc.) to help farmers secure their applications

- development of training (initial and continuing) and communication initiatives regarding innovative spraying technologies for crop protection products.

The UMT brings together researchers, engineers and technicians specialized in the viticulture field, agricultural equipment and sensors to achieve this work. Initiatives are carried out in close collaboration with equipment manufacturers (sprayers, nozzles and sensors), agricultural equipment technicians from chambers of agriculture and professional agricultural operators. This structuring project involving research, development and education stakeholders thus enables the development and rapid transfer of research results.

Under this UMT, a new tool—the EvaSprayViti artificial vineyard (*see p. 64*)—was developed to reproducibly characterize the agroenvironmental performance of vineyard sprayers and spraying practices using them. The first results of studies carried out with this tool confirmed that spraying optimization and precision spraying are very important levers to reduce pesticide use. Substantial differences in performance have been recorded depending on the type of material used and usage practices. Moreover, a marked and safe reduction in pesticide use requires a global approach at the crossroads between research in the fields of technology (agricultural equipment, sensors, ICTs), agronomy (breeding, epidemiology, cropping systems), economy and sociology (innovation appropriation).

▼ *Sprayers with collection-retrieval panels* © IFV



▲ *IRSTEA site, Montpellier centre* © C. Fatou

# Impact of biodiversity management in vineyards on Phytoseiidae predatory mite communities

Agrosystem diversification: (1) reduces food resources of specialist pests, and (2) boosts the diversity and sustainability of food resources and habitats for beneficial organisms. Studies carried out by the Centre for Biology and Management of Populations (UMR CBGP) are focused on generalist predatory mites (Phytoseiidae), the most efficient natural enemies in viticulture. The aim is to characterize the role of agroecological infrastructures at different scales (plots, environments surrounding plots) in order to propose agrosystem management options.

'Centred plot' approaches (agroforestry management of vineyards with pines and *Sorbus domestica*) have revealed that plant diversity does not lead to predator diversity. However, this does not affect biocontrol applications because the species observed—on both trees and grapevines—are efficient natural enemies. These studies also showed that the grapevine variety has a greater impact than agroforestry management on Phytoseiidae mite densities. Finally, although the co-planted trees serve as predator reservoirs, this effect must be modulated depending on factors such as competition, tree shade and pollen (quantity, type) disseminated on the grapevines and

whose impacts on Phytoseiidae densities have yet to be investigated. Several studies on the effects of the environment surrounding the vineyard have highlighted the presence of these predators, especially *Kampimodromus aberrans*, on nettle, fig, pubescent oak and red dogwood trees, indicating that these plants would be good candidates for sustainable management of vineyard agrosystems. Finally the 'landscape' approach launched in 2014 seems to show a relationship between the landscape complexity and Phytoseiidae and pollen density.

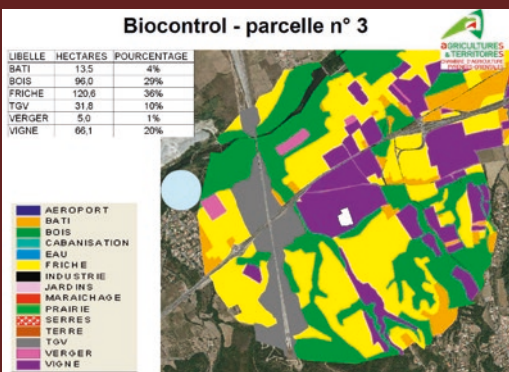
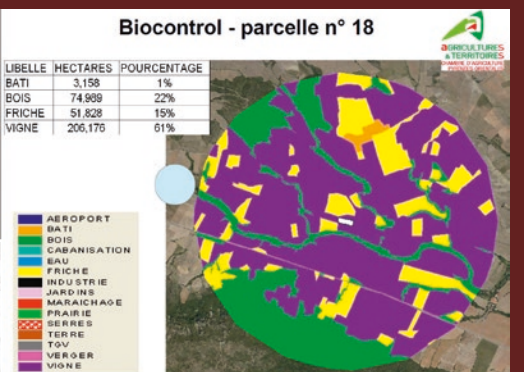
The potential effects of agroecological management are promising. Although these studies have led to some progress, many unknowns still have to be clarified concerning interactions between agronomic, ecophysiological and impact factors on Phytoseiidae mites. Future collaborations between researchers in different disciplines focused on different topics are needed to shed light on these unknown factors.

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## ▼ Two plot research sites with contrasted environments in Pyrénées-Orientales region (France)

© Chambre d'agriculture des Pyrénées Orientales



▲ *Phytoseiidae*  
 © G. Zriki/Montpellier SupAgro

## A Languedoc vineyard estate for vitiviculture training and development

*Domaine du Chapitre* is one of the two experimental wine-growing estates of Montpellier SupAgro. This estate, which is located at Villeneuve-lès-Maguelone, 10 km from La Gaillarde campus (Montpellier), covers a 130 ha area, including 35 ha of vineyards. Seven agents (INRA, Montpellier SupAgro) manage and maintain the vines and market the products. Teaching, experimental research and vitiviculture innovation transfer are handled at the plot and entire vineyard scales.

This estate—which was long devoted exclusively to grapevine breeding and the dissemination of new varieties—is currently involved in the conservation of genetic resources of 'the rarest vines' (repository with potted rootstock). The estate also hosts experimental plots managed by UMR AGAP for research programmes focused on genes of agricultural interest and selection of resistant parents. Finally, for UMT *Géno-Vigne*®, the

estate sets up and manages plots for studying the adaptation to climate change of foreign grapevine varieties. In partnership with IFV, it also propagates varieties from breeding programmes and disseminates them within the wine-growing sector.

*Domaine du Chapitre* has also been collaborating with UMR SYSTEM for over 10 years. The operational vineyard provides support for research programmes focused on agronomic viticulture practices, assessment of conventional and innovative viticulture system performance at the plot scale. This arrangement enables the analysis of different agricultural options geared towards reducing pesticide inputs in viticulture and the environmental impact of implemented cropping practices.

Since 2015, the estate has been involved in an ambitious project aimed at creating an operational site for digital viticulture at the vitiviculture estate scale and associate companies that implement the latest technological advances in agriculture (plot monitoring and



▲ *View of the Domaine du Chapitre*  
 © Montpellier SupAgro

management, running equipment and managing the material, work organization, vineyard management). This UMR ITAP coordinated project (see p. 48) already involves several partners, including Vivelys (a company that develops and provides advice on tools for the vitiviculture sector, hosted by the *Domaine du Chapitre* business centre) and SMAG (*Smart Agriculture*, which develops and publishes agricultural software in Montpellier).



# Knowledge for controlling wine quality

**M**aking wines that meet consumer expectations while taking new health quality requirements into account and reducing the environmental and climate change impacts are challenges addressed by research teams of the Agropolis viticulture and wine community. This is done by combining fundamental knowledge building on all aspects of the chain, from the vines to the glass. Highly targeted studies are focused on levers of action that could lead to technological innovations.

The research aims to generate knowledge that could be used to improve quality control regarding the products, as well as the winemaking and preservation processes. But the wine quality development process has to be clearly understood before it can be controlled. Molecules, blends and complex interactions between molecules—which researchers strive to unravel—underlie the characteristics of wine, including the colour, flavour, astringency, etc. In this framework, the teams develop programmes to gain insight into the mechanisms involved in the formation of key quality constituents such as phenolic compounds, flavours and polysaccharides. Knowledge on the organization of these systems and their responses to technological interventions (e.g. winemaking conditions) is essential for tailoring production and winemaking sequences. Precision oenology is also based on this knowledge and on mathematics for the development of prediction tools (see p. 47). The projects also take into account advances in innovative technologies, which broaden the range of tools proposed to winemakers for winemaking and wine preservation. Moreover, new constraints associated with the reduction of inputs and the impacts of climate change on wine characteristics are accounted for in these processes so as to mitigate their effects (see p. 57).

Fermentation microorganisms are also under the spotlight. Fermentation yeasts are a prime focus of research in many team projects as they play a key role in the winemaking process, while also impacting wine quality. As in other fields, research has been highly intensive on yeast genomes over the last decade. These studies have revealed how remarkably wine yeasts have evolved under oenological environment constraints into the current yeasts that are so well tailored and efficient for winemaking. In addition, the research has shed fresh light on the genetic basis of winemaking yeast properties (ability to ferment or form certain flavours). This will enable the development of new strategies to investigate biodiversity or improve yeast strains. The role of yeasts in wine flavour formation is also the focus of studies, ranging from specific aspects of their biogenesis to integrating them in fermentation management strategies.

All projects carried out on these topics are supported by a set of research and technical platforms (polyphenol, aroma and sensory analysis, fermentation room), which play a key role in this system. The tools are also fully accessible to economic stakeholders and help strengthen ties with partners. Many research programmes on these topics are thus being carried out in the framework of partnerships with companies or stakeholders of the sector, thus creating conditions that are particularly favourable for the transfer of innovations developed by the laboratories.

**Bruno Blondin (UMR SPO)**  
**Jean-Michel Salmon (UE Pech Rouge)**  
**& Rémi Guérin-Schneider (UMT QUALINNOV)**

# Knowledge for controlling wine quality

## Understanding the mechanisms involved in the wine quality development process

The joint research unit **Sciences for Enology (UMR SPO – INRA, Montpellier SupAgro, UM)** conducts research aimed primarily at generating knowledge to gain greater insight into mechanisms involved in the development of wine quality.

The first theme concerns the integrative physiology of winemaking yeasts and fermentation management. Winemaking yeasts have unique features within the *Saccharomyces cerevisiae* species as a result of selection induced by the oenological environment and humans. Research carried out by the research unit aims to gain insight into the mechanisms that could be involved in these evolutionary processes and to identify the molecular basis of the strain properties. The integrated functioning of the metabolism and the basis of the metabolic diversity are also studied. The knowledge produced is used to develop strain improvement strategies.

The alcoholic fermentation process is the result of interactions between yeasts, the must composition and fermentation control method (possible temperature adjustments, the addition of nutrients, etc.). The overall aim is to describe the course of alcoholic fermentation in fine detail using online monitoring systems, to model it and develop new control methods in order to optimize the fermentation kinetics and organoleptic features of wines. Complex yeast ecosystems, including non-*Saccharomyces* organisms, are also investigated.

The second theme concerns phenolic compounds constituting a large family of metabolites that have a key role in wine quality. The research aims to gain further insight into their structural characteristics and the mechanisms that generate these molecules (biosynthesis pathways, reactions that occur during technological processes), physicochemical interaction mechanisms involving these compounds with other

macromolecules (polysaccharides, proteins), and their impacts on the product quality or on the efficiency/selectivity of the technological processes involved. This knowledge is then used to develop new strategies for controlling technological processes (extraction, stabilization, etc.) and new applications of oenological interest. Moreover, applications are sought in other areas, especially for producing biomaterials.

Facilities of collective interest are grouped in an analytical platform (regional research and large technical platform) devoted to structural analysis and polyphenol interactions, and technical platforms (sensory analysis room, volatile compound analysis platform, biotechnology room).

Research projects—thanks to the integrated approaches with UE Pech Rouge and UMT QUALINNOV and strong industrial partnerships—can be efficiently conducted at pilot and preindustrial scales.

► *Automated control of alcoholic fermentation kinetics*  
© C. Verriès/INRA

### Main teams

**UMR SPO**  
**Sciences for Enology**  
(INRA/Montpellier SupAgro/UM)  
45 scientists

**UMT Qualinnov**  
(IFV/INRA)  
6 scientists

**Pech Rouge Experimental Unit**  
(INRA)  
6 scientists, 30 engineers and technicians

### Other teams focused on this topic

**UMR Physiology and Experimental Medicine: Heart – Muscles**  
(UM/INSERM/CNRS)  
51 scientists, with 5 involved in the topic



# Understanding the biosynthesis of aroma compounds during fermentation

Fermentation aromas, which have an important role on the aromatic characteristics of young wines, are synthesized by yeasts. These aromas belong to different chemical families, with the first and foremost being higher alcohols and esters. The metabolic pathways leading to their synthesis had mostly been clearly identified, but there were many lingering questions regarding their regulations and means of action to alter the synthesis of these compounds. UMR SPO addressed these questions by carrying out a multidisciplinary research study at:

- the yeast level, with the implementation of different approaches: studying metabolic fluxes using isotopic labelling, gene expression analysis (transcriptomic)

- the fermentation level, with precise monitoring of the synthesis dynamics (one point per hour) of the main aromatic molecules using online gas chromatography while determining the gas-liquid balances in order to calculate the total compound production.

These studies have led to major advances in understanding how the metabolism works, demonstrating: (1) the predominant share of the carbon metabolism in comparison to the Ehrlich pathway\* for the synthesis of higher alcohols and acetate esters, and (2) the key role of acetyl-coenzyme A.

A study of the combined effects of the main fermentation parameters (temperature, must nitrogen and lipid composition) also led to results of practical interest, with fermentation implementation conditions conducive to the production of fermentation aromas being recommended. This study was carried out in collaboration with the Lallemand company, which is now able to advise winemakers on the choice of strains as well as on the optimal implementation conditions.

*\*An amino acid degradation pathway and a major source of aroma in fermented products.*

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▲ Online gas chromatography © INRA

# Winemaking yeasts – genomes, history and evolution

*Saccharomyces cerevisiae* is the quintessential wine yeast. This species has been associated with human activity for millennia and can be isolated from natural environments. The use of yeasts for fermentation has gradually, over time, led to the selection of specialized strains with unique phenotypic features. The rapid development of high-throughput sequencing approaches recently shed new light on the evolutionary history of these strains and enabled studies on mechanisms that have shaped the genome of this species and adaptation to an ecological niche.

UMR SPO has conducted various studies in this context:

- by sequencing and analysing the complete genome of a first commercial wine yeast (Lalvin EC1118®)
- by conducting population genomics studies based on comparative analysis of the genome of 74 yeast strains of various niches associated with human activity (wine, flour, rum, bread, dairy products) and eight natural oak isolates
- by studying the phenotypic diversity of these strains during winemaking fermentation.

These studies have led to key advances in the understanding of the *S. cerevisiae* population structure, lifestyles and adaptive mechanisms by highlighting: (1) different genetic groups corresponding to different ecological niches, (2) horizontal transfers of specific winemaking yeast genes derived from distant yeast species and playing a key role in adaptation to their environment, (3) a diverse range of mechanisms (introgressions, gene transfers, amplifications, allelic variations) contributing to the genetic and phenotypic diversity of strains.

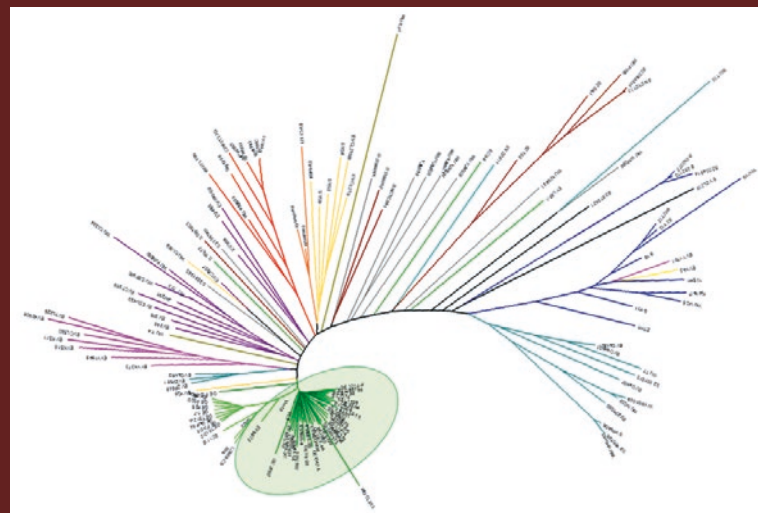
These genomic data represent a unique resource to clarify the factors underlying the adaptation to ecological niches and technological properties of strains, thus offering new opportunities for improvement.

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▲ Phylogenetic tree of *Saccharomyces cerevisiae*  
The wine strain group is circled.

© J.-L. Legras



◀ *Saccharomyces cerevisiae*

© S. Marsit

## Understanding the physicochemical interactions of tannins and their impact on wine characteristics

Physicochemical interactions—like biological, biochemical and chemical transformations—occur throughout the winemaking process and influence the composition and organoleptic characteristics of the end products.

For red wines, tannin interactions have a marked impact on wine quality (astringency, limpidity, colour stability, etc.) and on the efficiency of certain technological operations (extraction, fining, filtration, stabilization, etc.).

These interactions can occur in solution or at the interfaces (plant and microorganism cell walls, materials), and involve other (macro) molecules of wine or exogenous compounds (fining adjuvants, additives, salivary proteins in case of astringency).

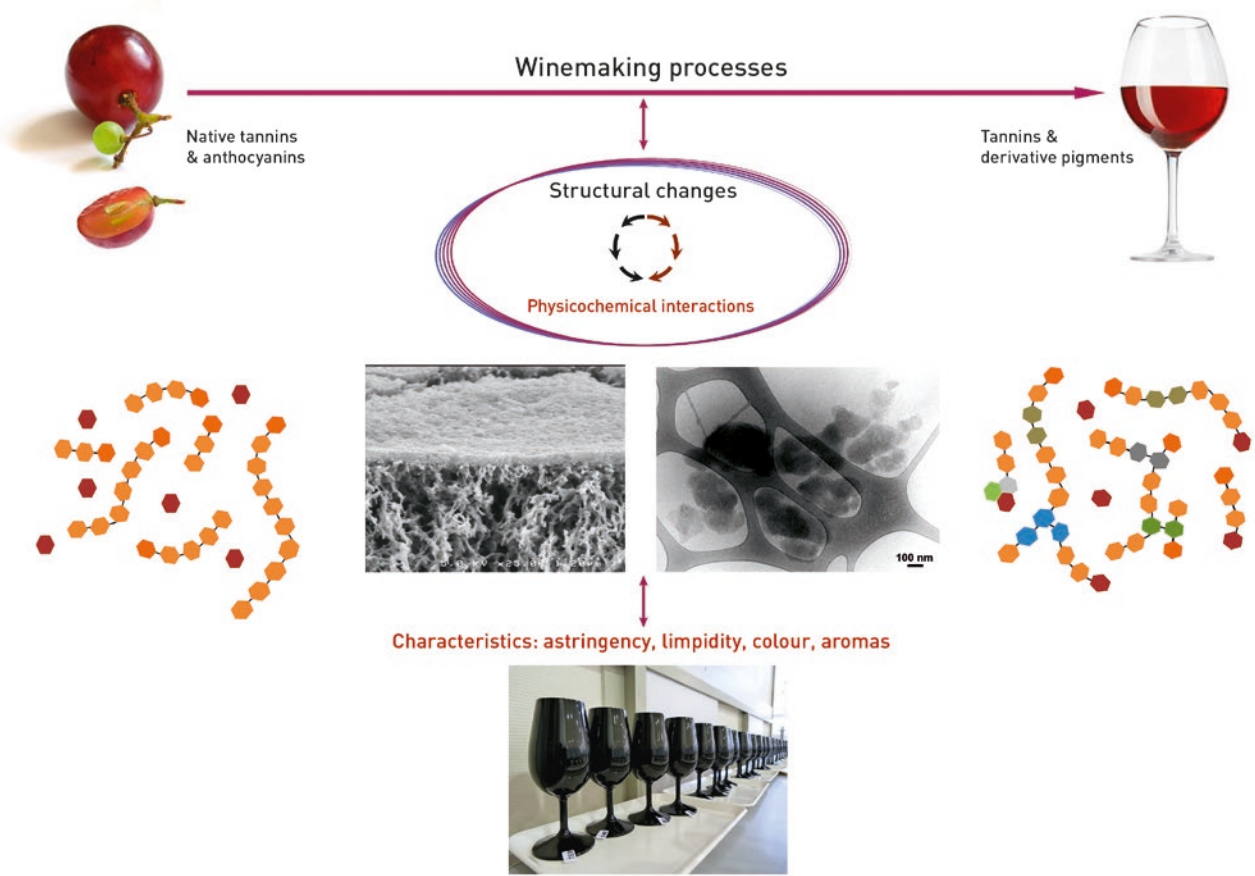
They are highly affected by the degree of polymerization, the conformation and nature of tannins. But the structural features of tannins extracted from grapes change substantially in wines because of their chemical reactivity. This leads to the formation of tannins and derived pigments (tannins/anthocyanin reactions) that have

different structures and properties than those of their precursors and which account for the majority of tannins present in the finished products.

The astringency sensation associated with tannin interactions, for instance, is often marked in young wines but decreases during ageing due to structural changes.

Research studies carried out by UMR SPO have shown that these changes are highly dependent on the initial composition, pH, dissolved oxygen management and generally the adopted winemaking methods. These studies also highlighted the potential impact of these changes on the conformation of tannins and their physicochemical properties (interactions in solution or at interfaces). The identification of the structures and mechanisms involved is used to develop innovative quality control processes and products.

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▲ *Structural changes in tannins and anthocyanins during winemaking and ageing—impact on their physicochemical interactions and wine features*

© A.Vernhet/Montpellier SupAgro



## Tannin oxidation markers to measure the oxidation status of wines

Oxidation is an increasingly important issue in the winemaking sector. Global warming (increased pH) and the reduction of inputs (decreased SO<sub>2</sub> levels) are conducive to oxidation phenomena, which modify the organoleptic quality of wines (colour, astringency, aromas) in an uncontrolled way. It is essential to gain full insight into these oxidation phenomena so as to be able to assess—and ultimately control—their impact on wine quality.

Characterizing the oxidation status of wine from a chemical standpoint and measuring it using simple methods is currently difficult because of the very high complexity of the molecular composition of wines.

In this setting, research carried out by UMR SPO is geared towards identifying oxidation markers that could be used to measure the oxidation status of wines. Amongst the constituents of wine, polyphenols are good potential markers from a quantitative and qualitative viewpoint. Tannins are the most abundant polyphenols in grapes, and are present to various extents in wines depending on the technological winemaking sequence implemented. These compounds are complex (polymers) heterogeneous structures and thus hard to analyse, which is why few studies have been focused on them with regard to their involvement in oxidation.

These studies have revealed the presence of oxidation marker structural motifs in tannins, with over 60 markers being identified. This method is to be automated in order to facilitate studies and systematic measurement of these markers in many wines. The aim of this high-throughput analysis is to assess the extent of tannin oxidation in the overall oxidation process in wines and to determine its impact on the organoleptic quality of wines.

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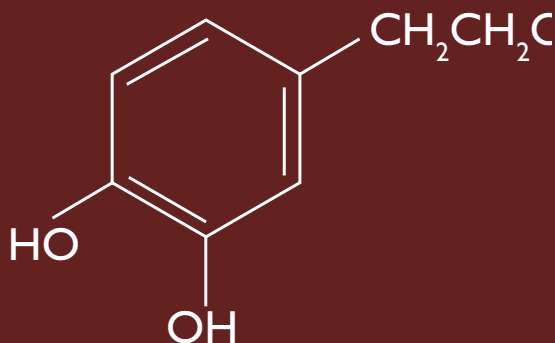


▲ Separation of phenolic compounds of wine, with yellow staining due to tannin oxidation

© F. Veran/UMR SPO

## Benefits of red grape polyphenols

Studies carried out by the Nutrition-Diabetes research team (Lapeyronie university hospital, Montpellier, France) in collaboration with the Physiology and Experimental Medicine of Heart and Muscles laboratory (PhyMedExp, INSERM-CNRS-CHU Arnaud de Villeneuve, Montpellier) aim to gain further insight into mechanisms involved in chronic disease development, especially insulin resistance and type 2 diabetes mellitus. The team thus focuses on the antioxidant and anti-inflammatory potential of red grape polyphenols for modulating insulin resistance, one of the obesity complications and a key mechanism in type 2 diabetes pathogenesis. Polyphenols are indeed able to modulate insulin resistance in animal models and cell cultures.



Promising results have been obtained in animals and humans under certain conditions. The (more controversial) results obtained in humans could be explained by interindividual variations in polyphenol transformation by intestinal microbiota (bacterial flora of the digestive tract). The latter enables 80% assimilation of polyphenols and modulates inflammation by lipopolysaccharides. Conversely, the microbiota composition depends on the dietary intake of polyphenols.

Studies carried out by the team thus aim to demonstrate that treatment with a polyphenol supplementation nutritional dose could enhance the insulin sensitivity of obese patients as compared to standard obesity care. As the absence of anti-obesity treatment demonstrated a satisfactory risk/benefit ratio, it is of interest to look for other ways of controlling insulin resistance, or even to help with weight loss.

This project is carried out as part of a partnership with the GRAP'SUD Union, which is specialized in producing and marketing grape-derived products. Medical validation of the benefits of polyphenol supplements would foster the development of derivative regional viticulture products.

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For further information on the PhyMedExp laboratory: <http://u1046.edu.umontpellier.fr/version-anglaise-2>



▲ Intra-plot zoning in a cv Syrah vineyard plot of UE Pech Rouge located in the Clape massif according to changes in the plant water status between flowering and maturity © INRA/UEPR

◀ Partial aerial view of UE Pech Rouge  
The photo shows vineyard plots located in the coastal zone (sandy and silty sandy soils) and all of the building facilities (technological experimentation halls, winemaking cellars, bottling hall). © INRA/UEPR

## Experimentation, innovation, diversification and sustainability in viticulture and oenology

**The Pech Rouge experimental unit (UEPR)** is the only research and transfer structure of INRA devoted to integrated research in viticulture-oenology. This platform enables a cross-cutting research approach ranging from the vineyard plot to the packaged product. Its task is to:

- design and organize experiments from the wine-growing sector in synergy with upstream research
- structure and carry out experiments or research associated with the wine profession
- ensure the transfer and development of the most innovative and relevant experiments by promoting information exchange with development stakeholders and by participating in student training (cellarmen and winemakers).

The unit's main focuses of research are as follows:

- the ecophysiology of grapevine and viticulture, including gaining a better understanding of and controlling grape quality. Since

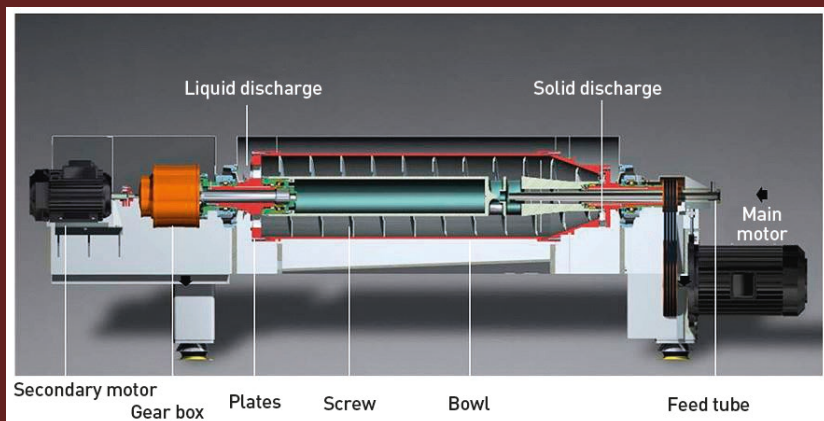
2010, as a regional, national and international viticulture testing platform, the unit has oriented its research according to the agroclimatic and social setting in the South of France—high temperatures, drought, high pH and potassium contents, reduced grape and wine acidity, irrigation, etc.—comparable to the setting in other wine-growing regions in the Mediterranean Basin and elsewhere, e.g. Portugal, Australia, South America and California. The unit's 38 ha of plots are distributed in three zones with different soils, so tests can be carried out under different levels of water stress, ranging from moderate to extreme drought.

- winemaking and processes aimed at proposing and studying innovative technologies that can be applied to different winemaking phases. The lines of research include studying the expression of the qualitative potential in grapes or wines, online monitoring and alcoholic fermentation management.

Research is conducted in 5 000 m<sup>2</sup> of buildings (technological experimentation rooms, winemaking cellars, bottling workshops, ageing and storage cellars) through 'product-process' oriented studies. Knowledge on the products is based on the analytical expertise of UEPR, UMR SPO and associated technical platforms, including the sensory analysis platform. The activities of the Innovative Technology-Oenology team, with the support of networks and partnerships (GMPA<sup>1</sup>, SPO, LBE<sup>2</sup>), are hinged on knowledge on processes and their impacts on grape juice and wine quality. The Viticulture-Quality Grapes team focuses on grape quality. Precise knowledge of wine compounds, such as quality markers, is enhanced through partnership projects with UMR SPO and UMT QUALINNOV (aromas and precursors, polyphenolic and polysaccharide compounds).

<sup>1</sup> UMR Microbiology and Food Process Engineering (INRA/AgroParisTech)  
<sup>2</sup> UR Laboratory of Environmental Biotechnology (INRA)

## Decanter centrifuge – a promising alternative to direct pressing for white and rosé winemaking



▲ *Cross-section of the decenter centrifuge* © Alfa Laval

from de-stemmed grapes in white and rosé winemaking processes. Qualitative extraction can be achieved at roughly the same yields as obtained with pneumatic pressing systems. The extraction features can thus be modified by adjusting the decenter centrifuge operating parameters, but also by installing additional equipment such as a grape homogenizer or a metering pump upstream of the centrifuge. The metering pump can inject antioxidants prior to grape burst, thus rationally and efficiently controlling must oxidation. Unlike conventional pneumatic pressing systems—where protection against must oxidation during pressing requires specific adaptations of the press (total inert gas blanketing or sulphite sprays within the press cage)—the major advantage of the decenter centrifuge is that various additives can be injected upstream of the centrifuge during extraction to control must oxidation. These antioxidants can thus act immediately upon grape cell compartment disruption. This is crucial because cell destructuring puts the three elements necessary for the initial oxidation reaction in contact—native phenolic compounds and polyphenol oxidase enzymes of the grapes, and atmospheric oxygen.

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The horizontal screw decenter centrifuge was introduced a few years ago in the winemaking sector. This technology was first tested for heat-treated grape must extraction because it can separate suspended solids from liquids. After a few technological modifications, it can now be used to directly extract must from grapes and is thus an excellent alternative to conventional pneumatic pressing systems. To assess its advantages in the winemaking process, UE Pech Rouge, in partnership with the company Alfa Laval, has been studying fresh grape processing using this technology since 2007. The main features of this centrifuge decenter are that it can be used in continuous mode and that the must extraction time is extremely short (residence time in the extraction bowl around one minute). It can thus be integrated directly for must-marc separation

## Preservation of white and rosé wines in Languedoc-Roussillon

Currently 40% of wines produced in Languedoc-Roussillon region (France) are exported, while the domestic market (60% of volumes) is strongly oriented towards supermarket distribution. These orientations have two production constraints, i.e. to obtain wines that correspond to typical consumer-friendly profiles, while guaranteeing qualitative regularity throughout the marketing year—which is problematic since the sought-after profiles seem to be qualitatively 'fragile'. Being able to offer tailored products year round is a challenge and various practices have emerged that range from the 'refreshment' of wines to the deferred vinification of cooled musts. The basic problem is, however, associated with aromatic and polyphenolic modifications that occur in wines during storage due to oxidation.

This programme, funded by the *Comité Interprofessionnel des Vins du Languedoc* and the *Conseil régional du Languedoc-Roussillon*, addresses the oxidation issue in an integrative way, from vineyard management to storage and conditioning. It proposes:

- to assess the intrinsic capacity of oxidation resistance of regional varieties and the viticulture levers (nitrogen nutrition, irrigation) to implement so as to enhance them, while incorporating studies on INRA resistant varieties (Pech Rouge site)
- to technically and economically develop and assess production processes tailored for these varieties
- to test new qualitative must extraction technologies.

UMT QUALINNOV—through a multidisciplinary approach that includes viticulture-oriented agronomy, technology, microbiology and analysis—is striving to develop integrated viticulture sequences to enable the development of wine profiles tailored to meet market expectations, while improving their preservation by controlling oxidation phenomena. This initiative, which has never been carried out at this scale in Languedoc-Roussillon, will help to better refine and characterize the composition of the raw material and thus to adapt winemaking technological processes to apply according to the material's qualitative potential and susceptibility to oxidation.



▲ *Rosé wine bottles displayed on backlit shelves* © INRA

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## Offering professional winemakers quality analysis tools for managing technological processes

The joint technology unit (UMT) QUALINNOV (IFV, INRA) conducts R&D programmes to develop new tools for characterizing the aromatic, polyphenolic and sanitary quality of grapes and wines.

The UMT aims to enhance knowledge on the development of qualitative features during grape production and processing, while providing the sector with access to tools and methods for managing these processes according to the typology of the requested product.

To fulfil these objectives, UMT QUALINNOV pools expertise in viticulture-oriented agronomy, oenology and analytical chemistry in order to contribute to the

development of quality wines and grape beverages that meet consumer expectations with regard to both sensorial (aromas, polyphenols) and sanitary features. It also benefits from experimental facilities at the UE Pech Rouge site plots, instrumented experimental platforms, and analytical resources, while also having privileged access to instrumental platforms at INRA in Montpellier.

The research conducted by UMT QUALINNOV is focused on:

- **Polyphenols:** the contribution of high-throughput spectrophotometry in the characterization and understanding of factors that determine the polyphenolic quality of wines:
  - adaptation of colour analysis developed for red and rosé wines
  - overall estimation of polyphenol families from the visible UV spectrum of a wine in acidic environments

- estimation of the astringency by a protein precipitation based method
- application of these measures in joint projects under way.

- **Aromas:** understanding interactions between aroma precursor compounds and microorganisms for the development of the aromatic potential of grapes and musts:
  - turbidity: link between the bioaccessibility of grape sterols, yeast viability and secondary metabolisms associated with alcoholic fermentation
  - nitrogen composition: impact on the revelation/degradation of amino acid type aroma precursors by yeasts and lactic bacteria.

### ▼ High-throughput measurement of red and rosé wine colour components by visible UV spectrophotometry

© M.A. Ducasse/IFV



## Technical platform for sensory analysis of wines and grape juice

The sensory analysis technical platform focuses on measuring and controlling the organoleptic qualities of wines and grape juice. It is primarily involved in research programmes of its two parent units—UMR SPO and UE Pech Rouge. An expert jury consisting of 23 selected and trained people (non-professionals in the wine sector) serves as its measurement tool. This unique feature ensures objectivity in their analyses because the judges are unaware of the research programme objectives. The facilities include two sensory analysis rooms: one room for the working group and an analysis laboratory with 16 individual cabins with online data input potential, all of which is managed by the FIZZ software package (Biosystèmes, Couternon, France).

The methods used are derived from sensory analysis standards and adapted to the programme objectives. They include the conventional profile (quantitative descriptive analysis), difference tests, Napping®, and the determination of perception thresholds.

The platform also has expertise in sensory and physicochemical data cross-tabulation via correlation or multi-criteria analysis (multiple factor analysis, etc.).

The platform was involved in different topics and conducted sensory assessments on the impact of winemaking processes (stabilization, clarification, yeasts strains, etc.), on the effects of wine oxidation and links with conditioning materials, on the impact of intrinsic compounds in wine (white wine bitterness, polyphenols, etc.), on the effects of viticulture practices (management strategies, water stress, etc.) and links between the typicity and wine-growing terroirs, new grapevine varieties resistant to fungal diseases or for the production of low-alcohol wines or low-sugar juices.

The team also provides training for university and engineering school students.



© G. Bouteillier



▲ Assessment of wines by an expert jury in individual cabins © A. Kerr

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## Polyphenol analysis platform

Phenolic compounds (often called polyphenols) constitute a large family of plant secondary metabolites. They are involved in plant dissemination and defence mechanisms and are essential for the quality of plant products. These molecules are especially abundant in grapes and wine, and include anthocyanins, which are red grape pigments, hydroxycinnamic acids, which are involved in enzymatic browning phenomena, tannins, and stilbenes (such as resveratrol).

The Polyphenol Platform (PPF) offers a range of approaches (mass spectrometry, nuclear magnetic resonance, spectrophotometry, chemometrics) devoted specifically to phenolic compound analysis. It provides support for the entire scientific community and industrial stakeholders, while offering technical and advisory assistance for partners and clients, mainly in response to two types of request:

- 1 identification and structural analysis of phenolic compounds
- 2 rapid analysis of the phenolic composition of a high number of samples (metabolomics, phenotyping, especially in connection with genetic breeding programmes or relative to studies on the impact of the environment and cropping practices on plant quality) or their processed products (authentication, process monitoring, property prediction).

PPF is involved in the European InnoVine project ('Combining innovation in vineyard management and genetics for sustainable European viticulture'). It also contributes to many industrial projects aimed at establishing links between the phenolic composition and quality, or predicting the impact of technological operations on these features. Some examples of recent work to support the sector include colour analysis of rosé wines (Centre du Rosé, IFV, UMT QUALINNOV collaboration), prediction of the colour of blended rosé wines (Nyseos company), prediction of the astringency of red wines (Pilotype project), studies on the impact of oxygen transfer through corks (Nomacorc company) or bottles (Novinpak project, see p. 42) on the wine quality.

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▲ View of the polyphenol analysis platform © N. Sommerer

# Bacchus

Enjeu

# Bacchus 2008

Enjeux, stratégies et pratiques  
dans la filière vitivinicole

Sous la direction de  
**Cyrille MANDOU**

Beysül AYTAÇ  
Thi Hong Vân HOANG

Préface de Sylvie TONNAIRE  
Rédacteur en chef de Terre de vins

## LE MANAGEMENT DU VIN

ENTRE TERROIR ET MONDIALISATION,  
UNE FILIÈRE EN PLEINE MUTATION

Sous la direction de  
Jean-Pierre Couderc  
Hervé Hannin  
François d'Hauteville  
Étienne Montaigne



Ouvrage dirigé par  
Julien **Granata** et Pierre **Marquès**

## COOPERATION COMPÉTITION

S'allier à ses concurrents pour gagner

## la vigne et le vin

sous la direction d'Hervé Hannin  
Jean-Pierre Couderc,  
François d'Hauteville  
et Étienne Montaigne

▲ Example of a few publications of social science  
researchers concerning the sector

© Montpellier SupAgro

# *Social science, innovation and sectoral transformation approaches*

**D**In a 'tradition-oriented' wine world, human science researchers in Montpellier (France) readily refer to historical figures such as Jules Milhau who first modelled wine prices in the first half of the 20<sup>th</sup> century. That was at the time when wine from the South of France—often considered simply as 'raw material'—was destined to accompany the industrial revolution and was seriously marked by the trauma caused by the post-*phylloxera* overproduction phenomenon that occurred in 1907. Economists thereafter monitored viticulture patterns, first by taking into account the official division (in 1935) between wines with an appellation of origin and table wines, as set out in the 'Wine Statute', which was a guarantee of regular support by unwavering public policies, even until present time with its inherent new challenges. It is in this setting that public policies, which are now—since the first common market organization in 1970—under European authority, are still being analysed, along with current aspects such as vine planting rights, which have recently been questioned.

It is hard to study wines from the huge Languedoc wine-growing region without conducting an in-depth analysis of the activities of its structures and stakeholders, including wine cooperatives, the first of which was founded by visionary vine growers from Maraussan in 1901. New analyses of the current cooperative setting in the 21<sup>st</sup> century are emerging: new governance arrangements, cooperative groups and subsidiaries, quests for new guarantees associated with local development, corporate social responsibility and sustainable production.

Some researchers have conducted studies on innovation processes and are active monitors of these changes, while others are more focused on the managerial approach, analysing 'coopetition'\* phenomena (see p. 44) and building collective reference frameworks that can be monitored between stakeholders within the same areas.

The winemaking sphere will soon, however, be globalized and economists in Montpellier—experts with a history of commitment to the International Organisation of Vine and Wine dating back to 1924—began studying changes under way over the last 20 years driven by 'New World' winemakers and the emergence of the World Trade Organization. Market globalization, concomitant to the profound quantitative and qualitative changes in national consumption patterns under way, has precipitated French wine companies into unknown waters concerning

marketing, export to new markets and the importance of 'brands', which until now have been quite discrete with regard to designations of origin in the French wine sector. Subsequent to findings of regular analyses on consumption patterns in France, international comparative studies were launched on visual codes, in addition to new semiotic analyses that highlighted the impact of different label designs on the purchasing habits of Asian consumers with very different cultural references.

Globalization has also prompted reconsideration of firmly anchored premises in the sector. France has refocused the spotlight on variables that link grapevine yield with the profitability of wine production units as a response to trends in competing products on world markets. Moreover, it has become clear that the usual wine innovation pathways taken since ancient times are even more numerous than initially perceived—ranging from grapevines resistant to fungal diseases to fermentation-inducing yeasts, AOC wines promoting 'terroir' flavours to wines with or without a geographical indication (GI), seeking a competitive edge on the world market, wines more tailored to meet the demand for 'natural' products, to viticulture practices capable of addressing the effects of climate change, which are already being felt and are forecasted to become even more severe.

These changes and innovations are supported and promoted by Montpellier researchers, including economic analysts, observers involved in systemic interactions (between stakeholders and disciplines), marketing advisers serving companies, and prospective analysts of the Institute for Higher Education in Vine and Wine Sciences (IHEV) responsible for forecasting the sector's future.

**Hervé Hannin (Montpellier SupAgro-IHEV)**

\* More or less long-term cooperation between competitors

# Social science, innovation and sectoral transformation approaches

## Innovation for agroecological and climatic transitions

The joint research unit **Innovation and Development in Agriculture and the Agrifoods Sector (UMR Innovation – INRA, Montpellier SupAgro, CIRAD)** conducts multidisciplinary research in France and worldwide on technical, organizational and institutional innovation processes. The research is focused on all processes, from stakeholders' innovation motives, to concrete ways to implement change, and to the impacts of these innovations on development.

The UMR has always conducted innovation studies on viticulture and wine. The first studies concerned the conditions needed to transform the sector in order to enhance quality at vineyard, wine cooperative, wine-growing region and market scales (geographical indications). Research was then reoriented towards innovations addressing challenges regarding agroecological transitions and climate change. The research unit has thus been instrumental in giving new impetus to research on:

- climate change: joint coordination of the Long-term Adaptation to Climate Change in Viticulture and Enology (LACCAVE) project (*see p. 58*)
- winegrowers' commitment to programmes to reduce pesticide treatments: DEPHY project—demonstration farm networks, experiments and production of benchmarks on low-pesticide input systems (*see p. 62*); and the Panoramix project—design and development of viticulture systems that combine resistant varieties and complementary crop protection methods (*see p. 63*)
- the evolution of wine-growing landscapes in response to these challenges in Mediterranean regions: the Mediterranean Landscapes and Terroirs project (PATERMED; *see next page*).

Researchers of this unit who participate in these projects share a systemic vision of innovation and conduct in-depth analyses on its economic, geographical, agronomic and sociological aspects. Innovation processes are thus pinpointed, analysed and sometimes supported (research-action projects), based on monitoring and surveys of stakeholders (wine growers, researchers, advisers, suppliers, etc.).

The research findings have confirmed the impacts of innovation and associated training networks on the competitiveness of vineyards and their ability to adapt to climatic and ecological issues. In all vineyards, collective action and interprofessional organizations have a clear role in different, and relatively efficient, ways. The research has also revealed that innovation is an inherent factor in different technological models that coexist in the sector (PDO labels *terroir*, technological PGI, organic agriculture, etc.). New types of collaboration between agricultural research and other stakeholders of this sector are even offered to address the need to combine practical and scientific knowledge according to the features of each vineyard.

### Main teams

**UMR Innovation  
Innovation and Development in  
Agriculture and the Agrifoods Sector**  
(INRA/Montpellier SupAgro/CIRAD)  
50 scientists, with 4 involved in the topic

**UMR MOISA  
Markets, Organizations, Institutions and  
Stakeholders Strategies**  
(CIRAD/INRA/Montpellier SupAgro/  
CIHEAM-IAMM)  
65 scientists, with 8 involved in the topic

**Wine Business Group**  
(Montpellier Business School)  
8 scientists





▲ *Grapevines uprooted in the Minervois wine-growing region* © E. Montaigne

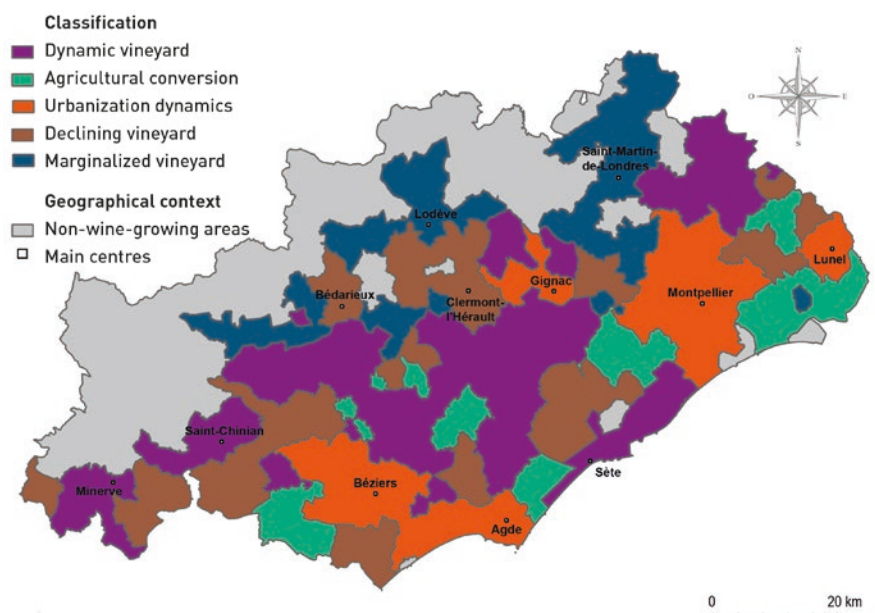
## PATERMED project – vineyard landscapes embedded in agricultural systems in Mediterranean France

The Mediterranean Landscapes and Terroirs (PATERMED) programme (2010-2014) aimed to analyse and promote vineyard and olive grove landscapes in the Mediterranean South of France. Research carried out in Montpellier by Innovation and AGAP joint research units, in collaboration with different teams\*, highlighted the cultural and operational quality of these landscapes at different geographical scales (from individual sites to the entire French Mediterranean area). Moreover, the studies revealed the processes that transform these landscapes: urbanization, fragmentation of agricultural areas, maintenance of wine- and olive-growing activities, uprooting, environmental issues, labelling and geographical indications, the development of tourism and recreational activities, etc.

The studies gained further insight into two topics of importance for wine-growing regions like Languedoc that are in the conversion process: agricultural, territorial and landscape impacts of vineyard land clearing; and the use of vineyard and olive grove landscapes in local development policies, especially in the *Pic Saint-Loup* and *Terrasses du Larzac* wine-growing areas.

A major contribution of PATERMED is the publication (in French) of the *Atlas des paysages de la vigne et de l'olivier en France méditerranéenne* (Ed. Quæ, 2014), which describes the different types of landscape and their changes as a result of issues such as urbanization, wine sector development and biodiversity, and heritage protection.

The results and deliverables of the PATERMED project, especially this landscape atlas, offer land-use managers and viticulture sector managers some food for thought and a decision-support tool to address landscape issues, which are also primary concerns for many local authorities.



▲ *Dynamics of a wine region* © C. Arnal, 2013

\* UMR TELEMME - Temps, Espaces, Langages, Europe Méridionale, Méditerranée (Aix-Marseille Université / CNRS) ; UMR ESPACE - Étude des structures, des processus d'adaptation et des changements de l'espace (CNRS / Aix-Marseille Université / Université d'Avignon et des pays du Vaucluse / Université de Nice Sophia-Antipolis) ; UR LOTERR - Centre d'étude et de recherche sur les paysages (Université de Lorraine) ; Afidol - Association française interprofessionnelle de l'olive ; Syndicat des vins de Côtes de Provence ; INAO - Institut national de l'origine et de la qualité.

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## Economy and management of the viticulture and wine sector

The joint research unit **Markets, Organizations, Institutions and Stakeholders Strategies (UMR MOISA – CIRAD, INRA, Montpellier SupAgro, CIHEAM-IAMM)** encompasses five social science disciplines economics, management, sociology, political science and anthropology. The unit has three teams focused on: research on consumer, agrifood, rural business and supply chain governance; coordination and policies for sustainable agriculture and food; and changing farming systems, household strategies and resource management.

The UMR conducts research on the common theme of sustainable agrifood and rural development in



▲ A researcher talking to wine growers at a *Université de la Vigne et du Vin* conference held in Ferrals-les-Corbrières (France)  
© Montpellier SupAgro-IHEV

developed and developing countries. It has a long tradition of collecting quality primary data via direct field surveys, underpinned by its large international cooperation network.

The fact that the teams are based in institutions with a strong technical component has enhanced interdisciplinary collaboration and awareness of the technical dynamics.

The wine theme has benefitted from an accumulation of knowledge and expertise on the economic aspects of this sector since the 1950s.

Economists are currently focusing research on:

- wine consumption, with participation in the national FranceAgriMer survey, which has been conducted every 5 years since 1980
- international trade, markets and the global economic situation with, over the last 20 years, annual publication of the Cyclope World Commodity Yearbook, as well as competitive and economic market summaries
- production structures—population, family, work, setting up of young farmers with: (1) an assessment of wine estates under way according to the level of pesticide use and crop insurance; and (2) an assessment of the economic and environmental performance of wine businesses, and characterization of the economic model that differentiates wines with a PDO label and those without a GI classification

- European wine policy via several assessments, supplemented by studies on vineyard clearing, vine planting rights and their impact on wine estate development patterns and income
- market launching, with studies on cooperation and negotiation, multinational corporations and groups, designing quality management contracts
- the dynamics of research-intensive innovations: dealcoholization techniques and disease-resistant varieties.

Management science specialists focus on the following topics:

- trademark rights, especially regarding the rights of the *Sud de France* collective
- product packaging and consumer responses to the emergence of novel products
- financial performance of businesses, especially cooperatives, and governance-performance relations
- regional viticulture economic information mapping
- foresight studies in the sector.

The Wine research team also takes part in the *Vin Montpellier* Group—an informal multi-institutional network focused on the economics and management of exchanges concerning wine-related research, expert groups of the International Organisation of Vine and Wine (OIV) and Vinelink International.

## Analysis of the commercial feasibility of launching Novinpak® bottled rosé

A project aimed at marketing and launching PET bottles is being conducted within the framework of a collaboration between UMR MOISA and the company Val d'Orbieu-UCCOAR (VINADEIS). This component of the 3-year Novinpak® project is focused on R&D aspects and on technical feasibility, with marketing aspects handled at the end of the project. The study on the commercial feasibility of this innovative packaging aims especially to analyse the reactions of potential consumers, perceived advantages and drawbacks. The aim is also to identify the purchasing and consumption conditions for an innovative product that is out of line with the traditional social codes regarding wine in France.

From a methodological and empirical standpoint, beyond the factual records and literature reviews on new wine packaging launches and innovations, four surveys were conducted from March to June 2014: two focus group surveys (experts and novices), an *in situ* survey involving interviews with 49 consumers questioned in the wine section of supermarkets and hypermarkets, and an online questionnaire survey (148 respondents).

Wine in PET bottles generally has a poor to very bad image associated with low grade or culinary wine. Novinpak® bottles are, however, attractive and considered esthetically pleasing, of trendy design, slender and elegant. The concept was considered suitable for a rosé product launch because this wine market segment is the one most open to new product launches and innovations. Surveyed consumers were not very concerned about the eco-friendly aspects of the plastic bottle, which were considered to be offset by the quality of the wine product. The convenience feature (lightness, solidity) was more recognized and valued by consumers.

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© Val d'Orbieu-UCCOAR (VINADEIS)

## STRATECOOP LR 2013 Programme Governance, strategy and performance of wine cooperatives in Languedoc-Roussillon

This study was carried out in the framework of a management PhD thesis at UMR MOISA in a setting marked by profound changes (vineyard clearing, trade globalization, mergers) and by an original governance system associated with the cooperative status. The findings shed light on changes under way regarding wine cooperatives in Languedoc-Roussillon (France) in terms of corporate governance, strategic positioning and performance. This provides wine cooperative professionals an accurate update of the situation, but above all effective management assistance and a prospective approach.

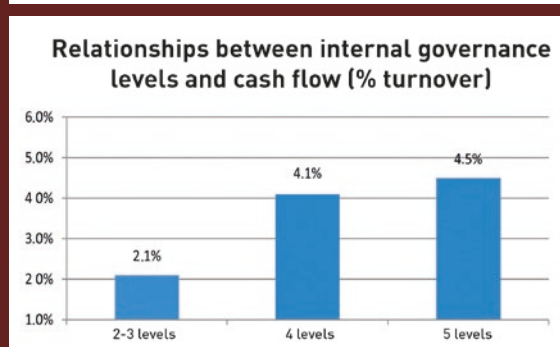
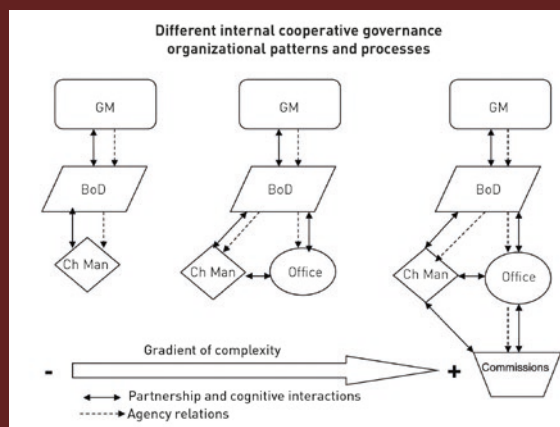
The study was based on a close partnership with the *Coop de France LR* and *Dyopta* (a company specialized in processing and analysing data from the computer-based viticulture registry), and on funding from France AgriMer and the *Compte d'affectation spéciale développement agricole et rural (CASDAR)*. It involved a sample of 87 wine cooperatives (45% of the total number of wine cooperatives in the region).

The STRATECOOP LR 2013 programme resulted in identification of the most effective trajectories for the regional wine cooperatives sector and for the sustainability of member vineyards. The results highlighted certain governance and commercial positioning options that were more effective than others in terms of upstream, downstream and financial performance. A typology was sketched out that remains to be specified in greater detail. Links were also established between the cognitive dimension of governance (decision-making process based on sometimes informal advisory bodies) and the long-term financial performance.

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For further information: Saisset L.-A., 2014. *Gouvernance, investissements immatériels et performance des entreprises coopératives agricoles. Le cas des coopératives viticoles du Languedoc-Roussillon*. Management science PhD thesis, Montpellier SupAgro. 607 p.



### ▲ Impact of cooperative governance on the long-term financial performance

Top: levels of internal governance: improvement of collective analysis.  
Bottom: link between internal governance levels and cash flow.  
Improvement of long-term performance. © L.A. Saisset, 2014

## PRECOVISION project (2009-2013) Economic performance of wine estates and reduction of pesticide inputs

A benchmarking method was developed by UMR MOISA to measure the economic performance of wine estates and assess possibilities of reducing pesticide inputs without changing the production technology, while shifting towards technology requiring lower pesticide usage.

This method enables multidimensional quantitative assessment of the performance of vineyards relative to all of those monitored, while also characterizing the most efficient and identifying those that could serve as benchmarks. It can also be implemented to find ways of improving the least efficient vineyards, especially from a technical standpoint, to reduce production costs and the use of polluting inputs. For public policymakers, this analytical framework facilitates measurement of the potential impact of regulations geared towards reducing pesticide usage according to the type of wine producer.

It was applied to survey data on viticulture cropping practices\* in Languedoc-Roussillon and Provence-Alpes-Côte d'Azur regions in order to assess the possibility of reducing pesticide input quantities—at least one pass and an average 15% of quantities used without any change in production structure, and at least two passes and an average 31% of quantities used when shifting towards another economically viable production structure.

The performance of wine estates is currently being modelled in pesticide input reduction situations for protected designation of origin (PDO) vineyards and those without a geographical indication (GI), which enables:

- characterization of economic models of PDO vineyards and those without GI
- assessment of possibilities for reducing pesticide inputs for PDO vineyards and identification of limiting production factors that hamper this reduction unless current practices or production technologies are changed
- assessment of economic and environmental benefits derived from a specialization in PDO wine or table wine versus coproduction of both types of wine at vineyard and territorial scales.

For the empirical part of the project, data from the Farm Accountancy Data Network (FADN, France). Several pesticide reduction scenarios will be implemented to assess the potential impact on wine estates according to the type of wine produced.

\* Service central des enquêtes et études statistiques (SCEES), 2008.

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## Vine planting rights

In 1935, France and Spain implemented regulations for controlling vine planting, which were 'temporarily' adopted by the Common Market Organisation for Wine in the European Union, with the exception of a short break (1970-1976). The definitive suppression of these vine planting rights (enacted in the 2008 reform), set for 2016 or 2018 at the latest, was highly justified but also highly rediscussed as the deadline approached, with many professionals and elected representatives fearing dire consequences—unbridled planting, market instability, smallholder producers, etc. A major study that was carried out by UMR MOISA for the European Association of Wine-growing Regions and the European Parliament (in collaboration with Italian universities) to focus on these key issues.

**Long-term case studies in Europe and the 'New World'\* enabled the team to:**

- 1 analyse the operational procedures of these regulations
- 2 test economies of scale associated with the size of wine-growing farms based on data derived from the Farm Accountancy Data Network in France
- 3 monitor the growth dynamics of these farms at the European level
- 4 address the main criticisms of vine planting rights.

**The study showed that:**

- 1 the size of the company is not a primary economy of scale factor, nor is the extent of income growth
- 2 the cost of vine planting rights does not significantly increase the cost of setting up a vineyard
- 3 a vine planting rights system, if used in a lax way, does not avoid overproduction (case of Alentejo, Portugal), and has negative impacts on compliant regions
- 4 the absence of a vine planting regulation system in the New World did not prevent the market imbalance
- 5 other countries have set up different market regulation mechanisms (Argentina)
- 6 the planting rights system did not make the wine region inflexible, but enabled reallocations in regions where there seemed to be increasing opportunities (France, Italy, Alentejo).

These results were confirmed by other studies carried out in Italy, Germany and Hungary.

\* Australia, Spain, Portugal and Argentina.



▲ Grapevine plants © M. Calleja

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Delord B., Montaigne E., Coelho A., 2015. Vine planting rights, farm size and economic performance: Do economies of scale matter in the French viticulture sector? *Wine Economics and Policy*, 2015. <http://dx.doi.org/10.1016/j.wep.2015.03.001>

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## A wine management research group

The **Wine Business research group of the Montpellier Business School** consists of teacher-researchers from the Montpellier Research in Management (MRM) laboratory. The research groups play a key role in the organization and development of research at the Montpellier Business School.

Research of the *Wine Business* group is focused on the wine industry with the aim of: (1) outlining the managerial implications for professionals in the sector, and (2) linking Montpellier research with the global academic community.

Meetings are thus open to professionals of the wine sector invited by members. The research findings are promoted with field managers in workshops, during interviews or in publications. Exchanges and visits of international professors and members of prestigious academic associations facilitate international recognition.

The research projects involve various disciplines such as entrepreneurship, strategic management, marketing and finance. Academic publications are mainly focused on co-competition strategies between small and medium enterprises (SMEs), consumer perception of wine label designs or innovative marketing channels,

such as websites. A recent collective publication has focused on wine sector management.

Publications of researchers of the group have received academic honours, such as the Best Paper Award at the Academy of Wine Business Research Conference or a PhD prize from the *Association pour les recherches en économie agroalimentaire*. Several joint research projects are under way in various areas: co-competition strategies between wine companies, Chinese wine consumer expectations, collective implementation of corporate social responsibility, the role of wine as a financial investment asset, etc.

## Social responsibility of wine cooperatives

This research project is focused on implementing a collective reference framework for corporate social responsibility (CSR) via wine cooperatives.

*Vignerons en Développement Durable*, an association of wine-producing cellars devoted to sustainable development which currently pools 18 cooperatives, was studied. Fifteen of these cellars participated in the study and 29 semi-structured interviews were conducted from March to June 2015. The interviews involved salaried executives as well as quality-control managers and/or vineyard managers in charge of CSR implementation. The study was aimed at understanding how cooperatives—sometimes competing—manage to unite to build a collective CSR frame of reference.

The diverse range of stakeholders involved in the collective effort—from cooperating wine growers to cooperative employees—foster the sharing of best practices and the adoption of innovative tools.

The study revealed that successful CSR implementation depends on the commitment of three types of stakeholders in the collective action—leaders of cooperative structures, cooperating wine growers

and employees. It showed that the collective CSR strategy was hinged on a cooperative identity backup strategy, providing a powerful tool for dialogue with key stakeholders. The research results concerned collective action management modalities and the impacts on stakeholder involvement.

This project involved researchers of the Wine Business Group (Montpellier Business School) associated with professionals of the wine sector.

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## Wine labels tailored for the Chinese market

Programme 6, cofunded by the French Foundation for Management Education (FNEGE) in the framework of the Junior Professor Award and by three Bordeaux wine merchants (*Maison Sichel, Cheval Quancard and Grandissime*), resulted in a study visit to China (in 2014) to gain insight into Chinese consumer preferences regarding wine label designs.



▲ Example of a pre-test carried out to select labels to test  
© Celhay, Cheng and Li, 2015

This market research was conducted by an associate professor of the Montpellier Business School and involved:

- a semiotic study on the design of wine labels in the 'imported wine' category on the Chinese market
- the creation of eight wine labels representative of different types of labels on the Chinese market
- a quantitative market research and a test of the eight created labels on 1 400 Chinese imported wine consumers
- drafting of a report—presented to the three wine merchants and FNEGE—of the market study results and recommendations to help them create wine labels tailored for the Chinese market
- writing of two academic articles based on the collected data.

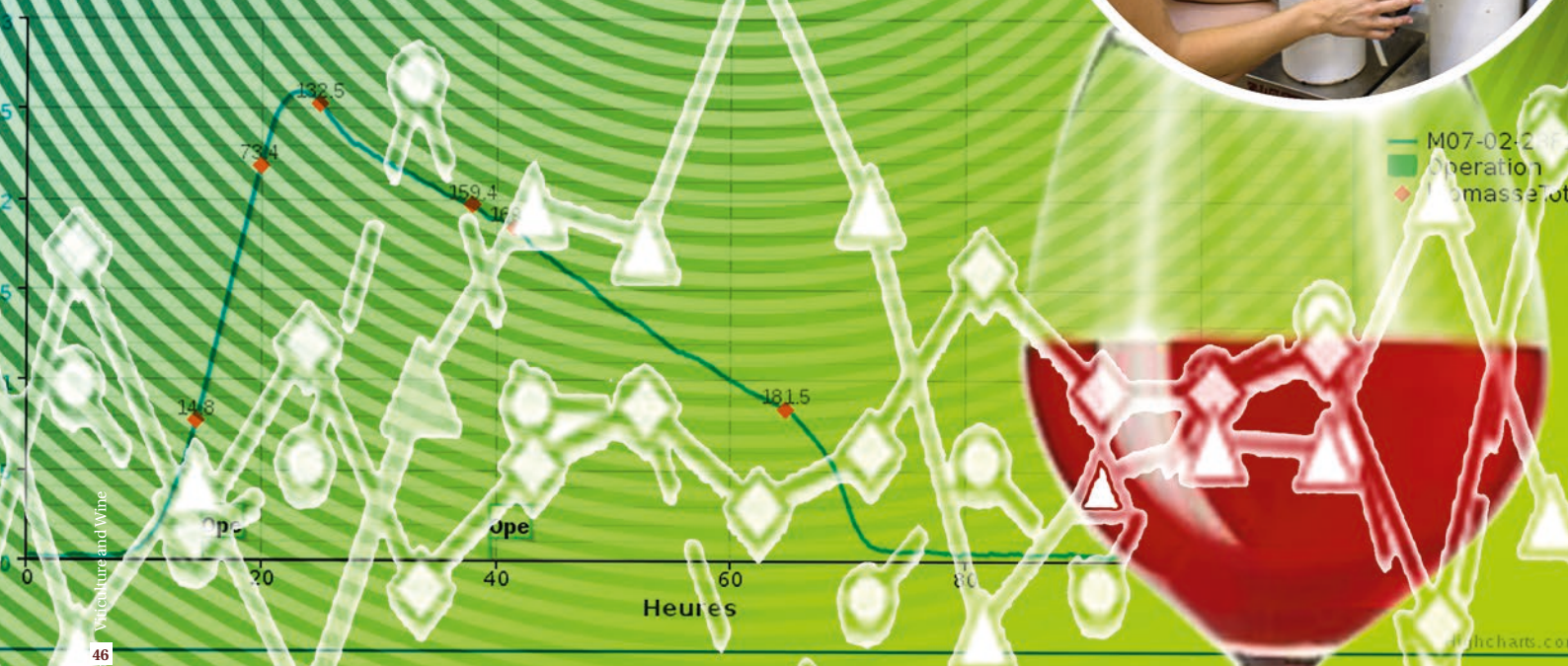
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▲ Wine labels selected for the quantitative study  
© Celhay, Cheng and Li, 2015



### Cinétique M07-02-28F25



# Meeting digital challenges in the sector

**T**he wine industry—like all business sectors—has undergone a digital revolution. This transformation has provided a unique opportunity for stakeholders in this sector to benefit from very high definition information and thus enhance monitoring and management of their production systems.

New technologies have led to a marked increase in data that can be acquired through wireless sensor networks or weather stations, machine-mounted or hand-held data logging systems, and remote-sensing platforms (unmanned aerial vehicles, airborne devices, satellites). Data concerning vines and the vineyard environment (climate, soil, etc.), as well as wine processing, making and marketing processes, are acquired at an unprecedented spatiotemporal resolution. This generates very high flows of diverse data which have to be processed, analysed, shared, disseminated and stored prior to their use and development. An incredible wealth of high volume data is now available, which could serve to design very effective decision support tools for the wine industry, provided professionals have access to tailored methods to develop their products in response to market trends and climate change. These methods must meet a dual challenge.

First, all upstream (agricultural and environmental) and downstream (transformation processes, consumption patterns, etc.) data must be linked via advanced data integration techniques, knowledge (disciplinary or business related) and models. Secondly, knowledge must be extracted from data by modelling and/or by inference on phenomena whose complexity has until now been hard to grasp. The tools and methods developed will facilitate assessment and management of new systems while ensuring the sustainability of the sector through an integrative approach. They will meet needs with regard to representation, diagnosis, assessment and decision support for various issues, including crop protection, environmental assessment, input management, product quality management, etc. New complex system design methods will also be proposed for innovations in, for instance, equipment sizing and types, while developing new cropping systems, breeding new varieties adapted to new constraints, and capturing new market shares.

The Agropolis scientific community has the expertise and facilities necessary to come up with effective responses to the major challenges of the digital revolution. They raise research issues for the entire viticulture and wine sector at organizational, spatial and temporal scales. Several research units are aware of the importance of digital challenges in the fields of agronomy and environment. They hence focus their methodological research—in collaboration with their national and international, public and private partners—on addressing the challenges that arise. The fact that specialized engineering science, mathematics and informatics research units, as well as thematic research units in viticulture, ecophysiology, oenology, etc., are pooled within Agropolis promotes interdisciplinarity and is a prime asset.

A first type of research concerns issues associated with measurements obtained via automated or manual recording devices. They encompass the design of: i) new sensors, ii) methods to ensure data quality, and iii) innovative systems for organizing and sharing information.

A second type of research deals with specific issues related to the influx of geolocalized data in the precision viticulture framework, e.g. the design of spatial data sampling and processing methods that take wine trade knowledge into account.

Finally, the last type brings together research in different areas: i) the analysis of huge volumes of heterogeneous data (spatiotemporal) collected in vineyards or wine cellars, ii) data- and knowledge-based modelling, and iii) simulation-based modelling.

A major share of the research conducted by the community in all of the fields presented in this chapter concerns the effective use of data via simulation and decision-support software packages, which are essential for identifying new uses and implementing innovative practices.

**Brigitte Charnomordic (UMR MISTEA)  
& Bruno Tisseyre (UMR ITAP)**

# Meeting digital challenges in the sector

## Development of information acquisition and usage tools and methods for decision support

Research carried out by the joint research unit **Information-Technologies-environmental Analysis-agricultural Processes (UMR ITAP – IRSTEA, Montpellier SupAgro)** fulfils needs regarding

| Main teams   |
|--|
| <p><b>UMR ITAP</b><br/>Information-Technologies-environmental Analysis-agricultural Processes<br/>(IRSTEA/Montpellier SupAgro)<br/><i>25 scientists, with 14 involved in the topic</i></p> |
| <p><b>UMR LIRMM</b><br/>Montpellier Laboratory of Informatics, Robotics and Microelectronics<br/>(UM/CNRS)<br/><i>170 scientists, with about 10 involved in the topic</i></p>              |
| <p><b>UMR MISTEA</b><br/>Mathematics, Informatics and Statistics for Environment and Agronomy<br/>(INRA/Montpellier SupAgro)<br/><i>18 scientists, with 11 involved in the topic</i></p>   |
| <p><b>UMT ECOTECH-VITI</b><br/>(IFV/IRSTEA/Montpellier SupAgro-IHEV)<br/><i>6 scientists</i></p>   |
| Other teams focused on this topic  |
| <p><b>Domaine du Chapitre Experimental Unit</b><br/>(Montpellier SupAgro/INRA)<br/><i>7 engineers and technicians</i></p>  |
| <p><b>UMR SPO</b><br/>Sciences for Enology<br/>(INRA/Montpellier SupAgro/UM)<br/><i>45 scientists</i></p>  |
| <p><b>Pech Rouge Experimental Unit</b><br/>(INRA)<br/><i>6 scientists, 30 engineers and technicians</i></p>  |
| <p><b>UMR LEPSE</b><br/>Ecophysiology of Plants Under Environmental Stress<br/>(INRA/Montpellier SupAgro)<br/><i>15 scientists, with 5 involved in the topic</i></p>                       |

information acquisition and its use in life science, agriculture and environmental applications. The research findings have many applications in viticulture—a field in which the team has developed substantial expertise on instrumentation and field experimentation.

UMR ITAP develops tools and methods applied to all stages from information acquisition to usage for decision support, including:

- development of new nondestructive sensors based on spectral properties of the environment (soil, fruit, leaves, etc.): the Optical Sensors for Complex Environments team develops scientific and technical benchmarks for characterizing agroecosystems by fine tuning optical sensors in hyperspectral imagery and near-infrared spectroscopy, and associated processing methods. The team has a state-of-the-art instrumental optics laboratory.
- design of decision systems tailored for sustainable agroenvironmental processes: the Modelling for Agroenvironmental Decision-making team develops scientific and technical benchmarks for designing decision-support system tools to diagnose system conditions and precision agriculture approaches. The methods involve fuzzy logic, discrete event systems and geostatistics.
- development of methods and tools to reduce pesticide use and impacts on the environment and on the health of operators and inhabitants in the vicinity of treated plots. The Processes-Environment-Pesticides-Health team studies spraying processes, from the spray nozzle to pesticide transport, on

catchment and territory scales. The team relies on the ReducPol technological research platform, which has unique experimental expertise and facilities in France devoted to studies on spraying phenomena and pesticide transfers in the environment.

The research unit has regular scientific exchanges with several international partners, including the Australian Centre for Precision Agriculture, the Universities of Sydney (Australia), Talca (Chile), Lleida, Pamplona, Madrid and Córdoba (Spain), etc.

The unit mainly conducts targeted research in close collaboration with various economic stakeholders, including private companies—startups, very small enterprises (VSEs), SMEs, medium-sized enterprises (MEs), large groups technical institutes on collaborative projects (ARVALIS, CTIFL\*, IFV, ITB) or regional experimental stations (CEHM)\*\*.

In public policy support missions, the unit conducts studies for national agencies (ONEMA, ADEME, ANSES\*\*\*), the French Agriculture and Environment Ministries and local authorities.

\* CTIFL: Centre technique interprofessionnel des fruits et légumes (France)

\*\*CEHM: Centre expérimental horticole de Marsillargues (France)

\*\*\*ONEMA: French National Agency for Water and Aquatic Environments  
ADEME: French Environment and Energy Management Agency

ANSES: French Agency for Food, Environmental and Occupational Health and Safety





▲ A drone photographing a vineyard

© G. Besqueut

## AgroTIC Services – ICT specialists offering technical expertise for wine companies

The digital world is constantly and rapidly changing. AgroTIC Services is a technical unit devoted to meeting the growing support and training needs of the wine sector regarding ICT issues. This specialized unit—coordinated by Montpellier SupAgro and UMR ITAP—was designed to serve as a clearly identified business partner to address all issues regarding the use of these new technologies in agriculture, especially in the wine sector.

Educational, support and monitoring activities carried out by AgroTIC Services enable companies to set up projects linked directly with teaching or research.

These activities are organized around four main foci:

- educational activities to strengthen links between education and business
- continuing education for agricultural professionals
- seminars for research stakeholders, students, agricultural businesses and ICTs
- individual business support on R&D projects in the agricultural ICT field.

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▲ Spectron™, a portable sensor for monitoring grape ripening © Pellenc SA

## Development of new portable sensors such as the Spectron™

VINNOTECH (2007-2012) was a major collaborative R&D project coordinated by UMR ITAP, pooling driving forces of public and private research.

The project aimed to integrate ICTs in all steps of the vine-cropping and wine-production process. ICTs ensure precise spatiotemporal information, real-time market reactivity and the creation of new viticulture and wine knowledge bases. These technologies facilitate the emergence of new products and services tailored for different links in the production chain. New sensors are used to effectively characterize the state of the vines, grapes and fermentations. This helps streamline the associated production process via decision-support services.

This project gave rise to a number of tools and services that are now (or about to be) marketed, including sensors for vine and fermentation monitoring. The Spectron™—one innovation proposed by the VINNOTECH project—is a portable sensor for monitoring grape ripening. This tool is used to autonomously monitor grape ripening parameters (sugar content, acidity, anthocyanins, etc.) directly in vineyard plots. The sensor is based on visible and near-infrared spectroscopy technology. It is the result of nearly 10 years of

collaborative research between UMR ITAP and the French company Pellenc SA.

The VINNOTECH project—certified by the *Qualiméditerranée* competitive cluster—was supported by the French government (Single Interministerial Fund [FUI]), Languedoc-Roussillon Region, OSEO and the European Regional Development Fund (ERDF).

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## Spatialization of viticulture data

Medium to high resolution spatial data are now widespread in the viticulture sector (GPS, onboard sensors, remote sensing, etc.). This phenomenon has generated a demand for advanced spatial information display, handling and processing tools. Due to the technical, social and economic features of the sector; it is essential to develop specific methods in order to provide the wine industry with easy to use, sturdy and inexpensive (or even free) tools that are tailored to specific trade needs. The following examples illustrate recent advances in this field.

### Optimizing spatial sampling

Spatial sampling—in an experimental or operational setting—is necessary to characterize the status of a vineyard plot at a given date. It is essential to carefully plan the sample number and positions in order to achieve quality estimates. High spatial resolution data (remote-sensing) helps determine the spatial variability of the studied area and thus to optimize the position and number of measurements to carry out. Research conducted by UMR ITAP aims to produce generic spatial sampling methods that are optimized and specifically tailored to viticulture parameters such as yield estimation using vegetation maps obtained by remote sensing imagery (UAV, airborne devices, satellite).

### Optimizing selective grape harvesting routes

Research studies are focused on complex optimization problems with specific applications to vineyards and wine cellars (LIRMM, ITAP and MISTEA collaboration). By integrating spatial data, these constraint programming methods address major logistical and organizational issues, like those regarding selective grape harvesting. This involves separately harvesting two qualities of grapes on the same plot with a two-hopper mechanical grape harvester. The location of quality grape zones and the estimated quantities to harvest are known. The problem is to optimize the route of the harvester in the vine plot, while addressing many constraints—consideration of the row harvesting direction, harvester storage capacity, etc.

### Mapping the water status in vineyards

Monitoring the vine water status on a plot, vineyard or territorial scale is essential to help wine growers make decisions with regard to managing the quantity and quality of the end product. Since 2010, UMR ITAP, with UE Pech Rouge and IFV, has been developing empirical models to extrapolate, spatialize and map the vineyard water status. The original aspect of the approach is that it makes effective use of point data acquired during operational monitoring of the vine water status. An innovative participative production approach (crowdsourcing) could be used with this method. Growers could thus share, consolidate and enhance a spatiotemporal database focused on monitoring the vine water status on a territorial scale. This would enable dynamic learning of a spatial model that is perfected gradually as the database is enhanced.

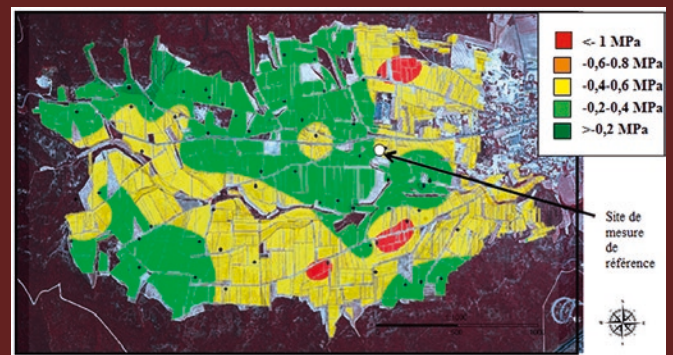
### GeoFIS project

Agropolis teams specialized on the development of operational methods have designed the free open source software platform GeoFIS to facilitate transfer of their research results. This simple scalable toolbox offers the possibility of adding new spatial data processing functions. GeoFIS is designed for quick transfer—through a simple interface—of innovative methods that can be implemented by professionals or students for specific applications. The functions developed in the framework of the GeoFIS project could be incorporated as plugins in GIS software.



▲ A drone photo of a vineyard

© G. Besqueut/UMR ITAP



▲ Extrapolation of a benchmark water status measurement (reference measurement site) at a given date and at the cooperative area scale

Interpolated map plotted on the basis of historical reference data—estimation quality at measuring stations not used for model learning (0.10 Mpa).

© UMR ITAP



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For further information on GeoFIS: <https://prezi.com/8f4gifshygl/geofis>

## Constraint programming and learning

The joint research unit **Montpellier Laboratory of Informatics, Robotics and Microelectronics (UMR LIRMM – UM, CNRS)** includes three departments: Informatics, Robotics and Microelectronics.

The Informatics department involves 14 project teams spanning a broad spectrum of informatics research, ranging from theoretical informatics to applications and interfaces with many other disciplines. The applications concern genomics, molecular and cellular biology, medicine, agronomy, biodiversity preservation, oenology and precision viticulture, etc.

Within the Informatics department, the COCONUT (Constraints, Learning, Agents) team is part of the Artificial Intelligence research platform, which proposes and studies artificial intelligence models and algorithms. This team focuses on problems arising through the use of technologies derived from constraint programming and learning, with a marked theoretical foundation and algorithm component. It deals with constrained optimization problems, especially numerical optimization, and standard learning or data mining issues with a constraint-based approach.

In the viticulture and wine field, several prototypes have been developed in collaboration with UMR ITAP and UMR MISTEA, and with the companies Nyseos and Fruition. These initiatives deal with various issues: optimization in selective harvesting of the route of a two-hopper grape harvester; optimization of the schedule and route of technicians for monitoring water stress in 200 vineyards; and optimization of the blending of several wines while taking volume and aroma profiles into account.

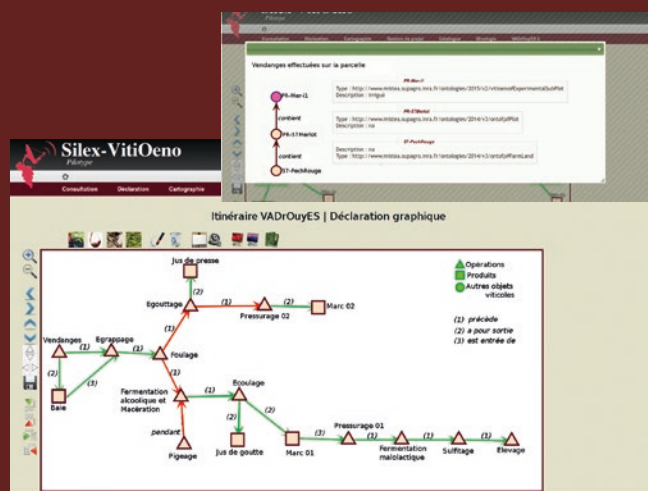
## SILEX project A promising information system for viticulture and wine experimentation

Since 2010, the collaborative Information System for Experimentation (SILEX) project, coordinated by UMR MISTEA, has been proposing information systems tailored to meet new data-related challenges for scientists and researchers. SILEX has led to the creation of several production information systems focused on viticulture and winemaking (UMR SPO, UMR SYSTEM, Pech Rouge UE).

SILEX can manage and temporally monitor entities such as plots, microplots, vines, organs, etc. Knowledge engineering and innovative semantic web technologies are used for this task. Domain-specific ontologies enable vocabulary control, event or transaction annotation, reasoning and data sharing, etc.

An annotation app for tablets and mobile phones is provided to improve the traceability. From a greenhouse, cellar or field, an operator can thus annotate entities identified by QR codes and declare a fallen pot or disease signs observed in a grapevine row. This can be associated with videos, audio recordings, photos or handwritten notes, and fermentation curves are enhanced by these annotations. Implicit or lacking events are also taken into account through business rules and reasoning. The knowledge produced can be exploited via statistical analysis treatments, and especially automatic data validation.

SILEX enables users to specify operations and products (grapes, must, etc.) in a production process. It visualizes this process while including associated data and analytical results, applied treatments, events, etc.



▲ Screenshots of *Vadrouyes*. A web application for the declaration and consultation of vinification (a) and viticultural (b) practices © UMR MISTEA

SILEX is widely used for bioprocesses (UR Laboratory of Environmental Biotechnology) and high throughput phenotyping of plants (UMR LEPSE). In this field, SILEX will equip nine platforms of the French national PHENOME project (see p. 55), ranging from the plot to the gene scale.

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### Experimental agricultural data – from organization to prediction and decision support

The joint research unit **Mathematics, Informatics and Statistics for Environment and Agronomy (UMR MISTEA - INRA, Montpellier SupAgro)** develops methodological mathematics and informatics tools for agricultural and environmental science applications. This unit pools researchers from the INRA Applied Mathematics and Informatics Division and the Montpellier SupAgro Department of Sciences for Agro-Bio-Processes.

MISTEA proposes innovative solutions to meet current challenges regarding the integration of experimental agronomic datasets that are increasingly large, heterogeneous and acquired at different scales. Synergies generated by the presence of computer scientists and statisticians with a broad range of expertise in data management, analysis and modelling enable the unit to implement an integrated approach ranging from

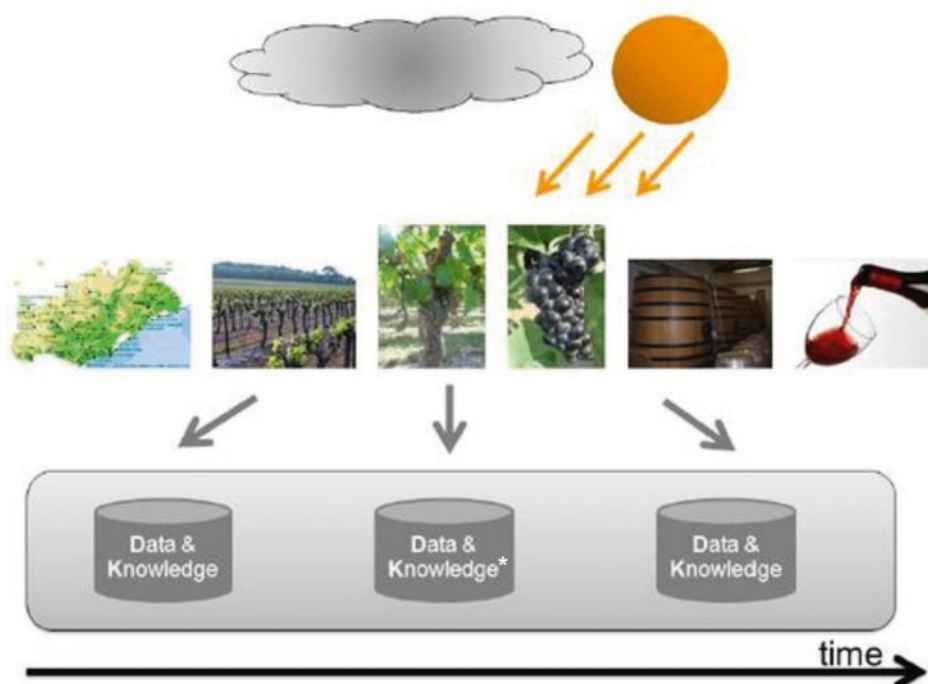
data organization to prediction and decision support. The viticulture and wine sector is a prime focus of the unit's research.

The unit proposes an original semantic graph based approach to collect and organize multiscale data from mixed sources. Ontologies\* enable the formalization of knowledge to facilitate sharing between different groups and the use of this information in automated reasoning. A large-scale study carried out recently with the Pech Rouge research unit resulted in the development and correlation of ontologies regarding viticulture and winemaking. Automatic data validation and preprocessing methods make it possible to combine expert information and statistical methods. An emerging prediction and decision-support challenge concerns the comparison of plant or fruit evolutionary data to a high number of cofactors, such as genetic or environmental information. MISTEA is developing advanced methods that combine curve analysis (functional statistics), high-dimensional statistics (variable selection), multiscale

integration (hierarchical models) and classification (clustering).

The research unit is involved with public and private partners in different projects in the sector: the 'Long-term adaptation to climate change in viticulture and enology' programme (LACCAVE, *see p. 58*), the 'Development of a decision-support tool to enhance the competitiveness of wines for export' project (PILOTYPÉ, 2010-2014) coordinated by a consortium of major stakeholders in the sector, and the 'Data integration and expertise for a new generation of viticulture tools' project (IDENOV, *see next page*), winner of the Global Innovation Competition in July 2014.

\*A computer model representative of a set of concepts within a domain and logical relations between them.



▲ A chain-based approach

© MISTEA

## IDENOV project Data integration and expertise for a new generation of viticulture tools



▲ Flow capture device © S. Payen/Fruition Sciences

The IDENOV project is coordinated by Fruition Sciences—a service company that provides wine growers with an integrative, terroir and vintage-specific, data-driven web application. The project is geared towards the integration of ‘data science’ innovations in the wine sector. It makes effective use of a highly diverse range of data from sensors placed in vineyards (sap flow and temperature sensors, etc.), associated with field expertise. Three partners are collaborating to achieve the objectives: Fruition Sciences, UMR MISTEA and Global Vision (a service support company implementing the open innovation strategy).

The project—through the development of a method tailored for the analysis of complex data—led to the development of a first prediction tool based on data collected in vineyards over several years.

The method combines multidimensional exploratory analysis techniques extended to temporal data and high-dimensional statistical methods that enable the construction of interpretable parsimonious models by estimating a limited number of parameters. This approach facilitates the discovery of periods and factors that have the greatest impact on grape quality (measured by physicochemical analysis) while building the founding elements of an automated decision support tool.

In the era of the digital revolution, and the massive influx of heterogeneous multisource data, this project is emblematic of the methodological advances achieved. The latter are geared towards tapping all of these data to build a new generation of tools for the viticulture and wine sector. The project was the winner of phase I of the Global Innovation Competition in 2014\*, in the Big Data challenge.

\* [www.entreprises.gouv.fr/innovation-2013/accueil-innovation-2013](http://www.entreprises.gouv.fr/innovation-2013/accueil-innovation-2013)

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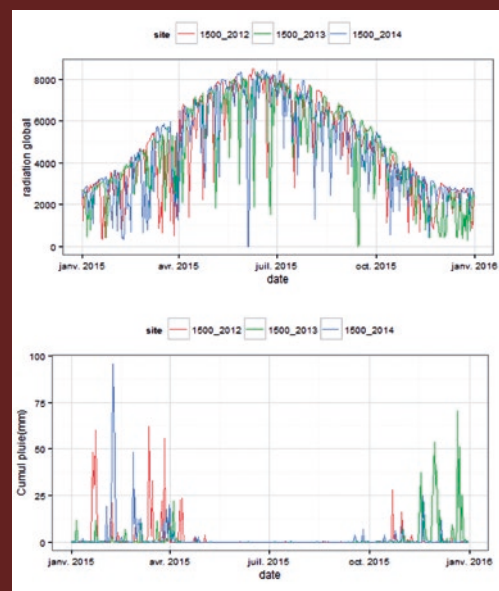
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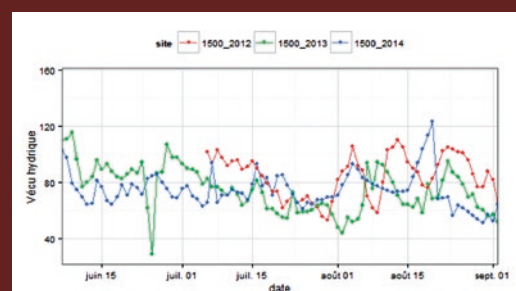


▲ Irrigated vines © S. Payen/Fruition Sciences

### Climate data



### Plant data



### Fruit data



▲ Correlating heterogeneous data at different temporal scales: weather data (sunlight, rainfall, etc.), vine water status, grape quality

© S. Payen/Fruition Sciences

## SOFA – oenological alcoholic fermentation simulation software

The SOFA software package—available in English, French, Italian and Spanish—is the result of a several year collaboration between the MISTEA and SPO joint research units. This collaboration resulted in the development of a physiological model of alcoholic fermentation. The model was validated with real data on several dozens of fermentations conducted in different conditions (sugar and nitrogen contents, temperature). The software is marketed by the company INTELLIOENO.

SOFA can predict the course of alcoholic fermentations (fermentation rate, time, sugar consumption, released energy, etc.) on the basis of a few initial key data, such as grape must analytical parameters (sugar and assimilable nitrogen contents) and fermentation conditions (temperature profile, nitrogen nutrient supplementation, fermentation onset date, tank volume).

SOFA is a two-part software package:

- SOFA 1 enables detailed prediction and viewing of the effects of key parameters (e.g. temperature, nitrogen content or nitrogen nutrient supplementation) on the course of alcoholic fermentation.
- SOFA 2 enables optimization of instantaneous and total frigorific requirements during the vinification process, as well as the tank occupancy (by adjusting the fermentation time).

SOFA is a pioneering example of modelling complex systems through a combination of data and knowledge related to the main physiological mechanisms of yeast and formalized by differential equations. The knowledge model is supplemented with many experimental data and the variables are dissociated so as to be able to identify the model parameters. SOFA illustrates the success of an

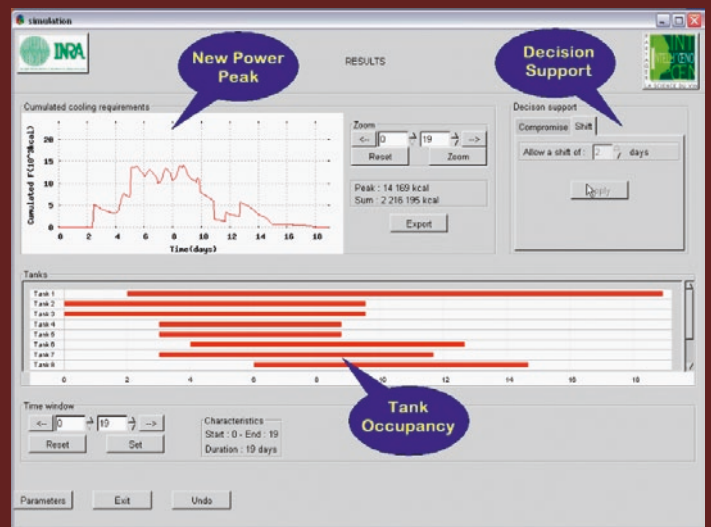
interdisciplinary approach in which mathematicians, microbiologists and computer scientists interacted in the research and came up with an operational solution. MOMAF (for 'modelling of the main reaction of alcoholic fermentation') is a very recent SOFA software extension that can simulate the kinetics of higher alcohols and esters.

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▲ SOFA software interface © B. Charnomordic





▲ ► *Tablet annotation of observations and events during vine experiments on the vine phenotyping platform in the field*

© A.Tireau/MISTEA



## PHENOME – the French plant phenotyping network

PHENOME (2012-2019) is a French National Biology and Health Infrastructure of the Investments for the Future programme. It aims to provide the French plant research community with a network of high-throughput phenotyping platforms (see p. 12), to facilitate characterization of the responses of genotype collections of different species to various environmental scenarios (associated with climate change)—many experiments have already been undertaken on grapevine. The infrastructure consists of: (1) two platforms under controlled conditions, (2) two field platforms under semi-controlled environmental conditions, and (3) three field platforms under non-controlled conditions.

All of the platforms are equipped with a complete set of functional 3D imaging techniques, for: detailed imaging of roots and shoots under controlled conditions, canopy imaging with an autonomous *phénomobile*, which captures functional 3D images of individual plots, and drones which capture images of hundreds of plots together. Two omic platforms also centralize metabolomic and structural measurements associated with experiments.

Two methodological projects coordinated by UMR MISTEA develop infrastructure for methods and techniques capable of: (1) organizing data from different platforms so that they can be stored and analysed over a long period by a broad ranging scientific community, and (2) designing and disseminating—to the academic community and industry—a new set of methods for data analysis and the extraction of genotypic traits (data annotation and validation, modelling, links with plant and crop models).

PHENOME has already led to the creation of phenotyping and precision agriculture SMEs (including one spin-off and several patents). It is incorporated in European and international phenotyping projects (European Plant Phenotyping Network, International Plant Phenotyping Network, European roadmap).

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► *Banyuls vineyard,  
Pyrénées-Orientales  
region, France*  
© C. Maitre/INRA



# *Interdisciplinary programmes to address challenges in the viticulture and wine sector*

**A**dapting to climate change, reducing pesticide use to preserve health and environment, improving wine quality to meet changing market needs are major issues upon which Agropolis viticulture and wine research is focused. Research teams are addressing these issues by focusing on specific questions concerning individual scientific disciplines (see previous chapters), while also consistently incorporating its expertise in more globally oriented approaches. The latter combine different levels of analysis, often ranging from grape genes to wine consumption, while taking different types of initiatives that economic stakeholders could implement in the short, medium or long term into account.

Interdisciplinary programmes are developing to cope with these issues, combining genetics, agronomy, oenology, economics, sociology, etc. These disciplines are combined to gain further insight into biological, technical and socioeconomic processes so as to improve wine quality, adapt to climate change or reduce pesticide use within a vineyard or sector. Interdisciplinarity is also favoured to develop new assessment methods, simulation tools or foresight studies, as illustrated by operations carried out in collaboration with IHEV and France AgriMer on low-alcohol wines and in the adaptation of vineyards to climate change for 2050. Finally, interdisciplinarity has become necessary to generate expertise and support for innovations that must be designed and developed while taking the context of their implementation into account.

This chapter illustrates this more cross-cutting and interdisciplinary type of research that is organized to address major challenges in the sector, often in association with economic partners wishing to innovate or anticipate potential changes. Climate change adaptation is also generally dealt with as part of the national LACCAVE project (see p. 58), which brings together many Montpellier-based researchers. In addition, complementary projects help specify the different combined innovations

possible for adaptation—breeding drought resistant varieties, yeasts or technology to reduce the alcohol content, new water-efficient management strategies, precision irrigation with waste water, etc.

Low pesticide and sustainable viticulture approaches also involve research on new grape varieties, particularly those resistant to mildew and powdery mildew. However, such varietal options are only of interest if accompanied by research on agricultural practices, soil management, or decision-support to enhance phytosanitary intervention management, etc. Such operations combine the assessment of cropping practices with new tools for monitoring the status of grapevines and their ecosystem.

Finally, new technical pathways are being explored to come up with innovations to enhance the quality and diversification of viticulture and wine products. These techniques could improve the quality of existing wines or broaden the product range through better vinification control associated upstream, for instance, with grape quality management via irrigation. The sector could, however, also be diversified beyond winemaking through the production of new grape juices or biomaterials. Researchers are thus generating a more comprehensive view of the potential future of viticulture by, for instance, promoting quality of *terroir* wines, but also by investigating new products that could be attractive to consumers.

**Jean-Marc Touzard (UMR Innovation)**

# Adaptation to climate change

Climate change has many impacts on vines and wine, which may be beneficial or not depending on the region, e.g. advanced harvest dates, greater water stress, wines that are more alcoholic, less acidic or with new flavour profiles. These impacts are bound to increase and potentially affect the competitiveness of vineyards and their geographical distribution.

The LACCAGE project (2012-2016) is studying the impacts of climate change on vines and wine and possible adaptation strategies for French wine regions. Twenty-three research laboratories have combined their expertise in different disciplines (climatology, genetics, ecophysiology, agronomy, oenology, economics and sociology), including 11 research units of INRA Montpellier, along with UMR Innovation.

The project has developed a systemic view of wine technical and value chains so as to be able to analyse climate change impacts and the diversity of potential adaptation levers. This analysis is conducted at several scales (plant, plot, farm, regional wine growing area and sector), while focusing especially on local levels where adaptation strategies can be coordinated.

Studies are focused on the physiological and genetic basis of vine responses to climate change parameters (temperature, water), technical innovations that could contribute to adaptation (new varieties, vineyard management, irrigation and oenological practices), choices of vine locations and effects on the landscape, costs and benefits for growers, and consumer views on 'climate-change wines'.

Scientists working on the LACCAGE project are also conducting foresight studies for 2050. Four scenarios have been proposed to fuel the debate and identify potential strategies: a 'conservative' scenario that only incorporates marginal changes; an 'innovation to stay' scenario which paves the way for a broad range of innovations on all vineyards; a 'nomadic vineyard' scenario which highlights vineyard relocation possibilities; and a 'liberal' scenario which tests 'everything is possible everywhere' situations.

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▲ LACCAGE project researchers in the field at Banyuls-sur-Mer (France) © E. Delay

## Selection of varieties and clones adapted to global warming

The global warming trend in recent years has led to earlier and earlier grape harvests and the production of wines with a relatively high alcohol content. Public health preservation measures and changing consumer tastes have prompted research on more supple and easy to drink wines with a reduced alcohol content.

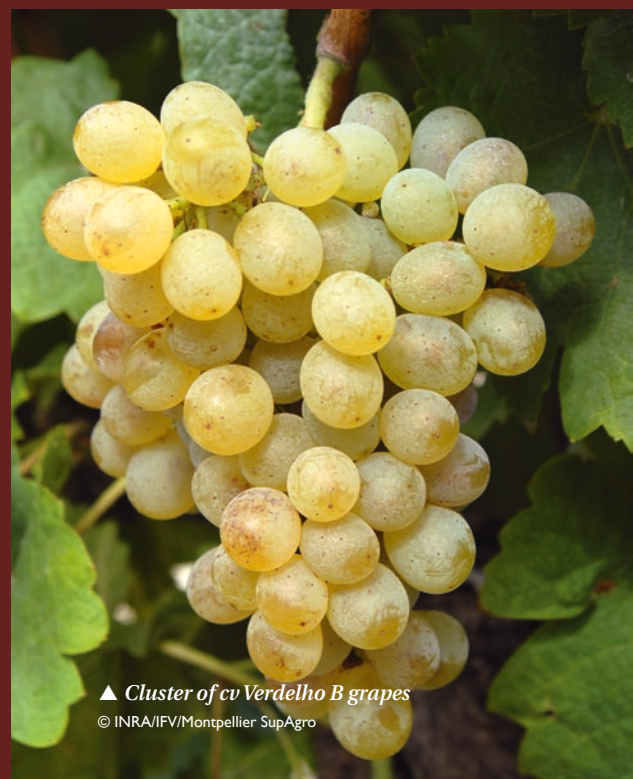
The aim of this research is to select varieties—local, foreign or *de novo*—and clones that could be harvested later or that would naturally accumulate less sugar and tolerate acute water stress conditions. To this end, studies carried out by *Sélection Vigne* partners are aimed at setting up a network of experimental plots, and ultimately registering new varieties in the official French national catalogue, while obtaining approval for new clones in the coming years.

Most of the recently registered varieties are from the Mediterranean Basin. Around 15 foreign wine grape varieties that are especially promising from quality and agricultural standpoints have been selected since 2010 on the basis of aroma, alcohol content, acidity, colour, polyphenol content, dry soil adaptation, structure, hot climate adaptation and lateness features. A complete list of these varieties and detailed characteristics of each one are available on the 'Catalogue of Vine Varieties and Clones Grown in France' website\*.

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▲ Cluster of cv Verdelho B grapes

© INRA/IFV/Montpellier SupAgro

## Dealcoholization and acidification – the contribution of post-vinification membrane technologies

Climate change induced modifications in wine quality trigger an increase in alcohol content and pH.

Lowering the wine alcohol content has been experimentally studied by INRA, UE Pech Rouge in partnership with the company Pernod Ricard, the *Fédération nationale des vins de pays*, UMR SPO, IFV and the company OENODIA ('Low Alcohol Quality Wines' programme, with ANR 2006-2009 funding). In a combined membrane process, the first dealcoholization step (reverse osmosis or nanofiltration) separates wine constituents by removing ethanol in hydroalcoholic permeate form. The second step, using a membrane contactor, partially extracts the permeate ethanol fraction according to the osmotic evaporation principle using water as solvent, with the pores of the used membrane being air-filled (hydrophobic material). Both steps are conducted in a continuous cycle, with the permeates being dealcoholized gradually as they are produced and gradually fed back into the wine during processing. A reasonable dealcoholization limit of -3% (vol) is set for the combined membrane process. Partial 20% dealcoholization relative to the initial alcohol content is recognized by the International Organisation of Vine and Wine (OIV) and now approved by the European Community.

The high pH of musts and wines has prompted oenologists to look for technical ways to acidify wines. High pH is mainly due to the presence of excess potassium. On an electrodialysis apparatus, potassium is specifically extracted through a cationic membrane, with displacement of acid-base balances of organic salts achieved through a bipolar membrane, which induces continuous and controlled wine acidification through pH measurement. This treatment can be carried out on centrifuged must, centrifuged wine, wine carefully racked after the end of fermentation or prefiltered at 25 µm. The electromembrane process for must and wine acidification was recognized as an oenology practice by OIV in 2010, and authorized by EU in 2011. The company GEMSTAB provides an acidification correction service in Languedoc-Roussillon region (France).

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▲ A mobile OENODIA-GEMSAB unit © OENODIA

# Domaine de Pech Rouge



**10 % Pech Rouge ROUGE**

Ce vin est conditionné en carton de 6 bouteilles. Récolté dans de bonnes conditions de maturité, puis vinifié de façon classique, ce vin a été abaissé jusqu'à un degré de 10 % vol à l'aide d'une technologie membranaire, dans le cadre d'un programme de recherche.

**CEPAGE :**  
 Marselan 70%  
 Merlot 30%

**VINIFICATION :**  
 Vinification traditionnelle avec remontage ou pigeage, cuvaison courte et contrôle au niveau de la température afin de préserver la fraîcheur aromatique du vin.  
 Temps de garde : 2 ans  
 Mets/vin : grillades



**10 % Pech Rouge BLANC**

Ce vin est conditionné en carton de 6 bouteilles. Récolté dans de bonnes conditions de maturité, puis vinifié de façon classique, ce vin a été abaissé jusqu'à un degré de 10 % vol à l'aide d'une technologie membranaire, dans le cadre d'un programme de recherche.

**CEPAGE :**  
 Chardonnay 50%  
 Muscat petit grains 50%

**VINIFICATION :**  
 Pressage direct puis vinification à basse température (18°C) afin de préserver les arômes.  
 Temps de garde : 2 ans  
 Mets/vin : apéritifs ou plats exotiques

▲ Wines dealcoholized by combined membrane techniques – the 10% Pech Rouge range of wines  
© INRA



## Selection of low alcohol yielding yeasts

Overcoming the increase in alcohol content in wines is a major challenge for the wine sector. This rising trend, associated with changes in oenological and viticultural practices and exacerbated by global warming, has been noted in most wine producing countries over the last 20 years. Excess alcohol can be detrimental to the sensory quality of wine, problematic for successful fermentation, while reducing the market competitiveness of wines because of the higher taxes based on alcohol content levied in some countries. Moreover, a reduction in wine acidity also often accompanies these changes.

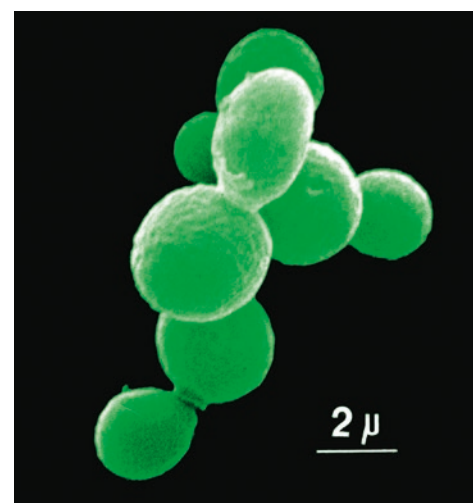
UMR SPO has been conducting research for more than 20 years with the aim of developing *Saccharomyces cerevisiae* wine yeast strains that produce less alcohol. This involves redirecting the yeast metabolism towards other by-products, without accumulating unwanted metabolites, while preserving the performances of the strain. This represents a major scientific challenge. Studies recently carried out by the research unit have been based on the development of an adaptive evolution strategy combined with a hybridization approach in order to redirect sugars towards glycerol production at the expense of ethanol. It was possible—by maintaining a wine yeast in extended culture in potassium chloride laced medium—to select an evolved strain having a sugar metabolism partially diverted towards glycerol, 2,3-butanediol and succinic acid. In tests conducted at different scales (laboratory, pilot, cellar), it was found that wines made with this yeast had a 0.5-1.3% (v/v) lower alcohol content, low volatile acidity and high total acidity.

This research, carried out in partnership with the company Lallemand, led to the selection of a yeast that is an effective tool for managing the alcohol/acidity balance in wines, thus addressing issues currently impacting wine producing countries in hot regions.

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▲ Germination of *Saccharomyces cerevisiae* yeast spores (electron microscopy)

© J.-M. Salmon / INRA

## Recycled treated water for vineyard irrigation The Irri-Alt'Eau project

The Irri-Alt'Eau R&D programme—designed to provide quantity- and quality-controlled water resources from an alternative source for vineyard irrigation—aims to highlight the feasibility of a new vineyard microirrigation practice using recycled treated water from urban water purification plants that would otherwise be discharged into the environment via the sea or canals. The research part of this project combines, over a water-soil-plant-grape-wine continuum, two INRA research units—LBE\* (Narbonne) and UEPR—and Veolia Environnement, Veolia Eau région Méditerranée (project coordinator), the company Aquadoc (irrigation system specialist), the Cave coopérative de Gruissan and La Grand Narbonne, owner of the Gruissan and Narbonne Plage water purification plants.

Urban and agricultural water tapped from the Lastours Canal is used to irrigate grapevine control rows in two cv Viognier and Carignan vineyard plots. The project is being implemented at several scales, from experimental plots—1.5 ha (UEPR site), 10-30 ha (Cave coopérative de Gruissan)—to the Gruissan vineyards (150-200 ha planned) and several other French wine-producing regions (Languedoc-Roussillon and Provence-Alpes-Côte d'Azur), with go/no go decisions made at each stage.

During the initial experimental stage, the quality of the recycled, prefiltered and UV-treated water is constantly controlled. Compared with drinking and agricultural water, this recycled water has higher salt and nutrient (nitrogen and phosphorus) contents. Supplementary fertilization could thus be substantially reduced in the medium- to long-term depending on the supplied water volume. The microbiological quality of the water is controlled by combined UV/chlorine treatments.

Through this project, the town of Gruissan will have alternative source of local water to irrigate grapevines and other crops, as is already done in other countries (Australia, Spain, USA, etc.).

This research programme (2013-2016) has been granted a prefectural authorization (2013 191 0007 of 11 July 2013). It has been accredited by the French Water Cluster (*Pôle Eau*), supported by *Transferts-LR* and it benefits from public funding (European Agricultural Fund for Rural Development, *La Grand Narbonne*, *Rhône Méditerranée Corse Water Agency*, *Languedoc-Roussillon Region*, *Regional Innovation Fund [FRI]*).

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## Managing wine quality in vineyards

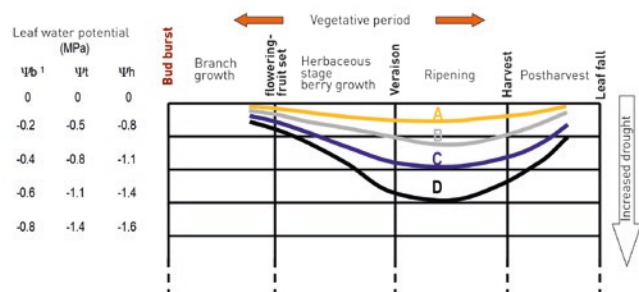
Continuous adaptation of grape cropping techniques in Mediterranean vineyards is essential to deal with climate change and the current wine crisis. This situation has paved the way to the development of new coping concepts such as irrigation, breeding of new grape varieties, development of new vineyard management systems, diversification and the use of sensors. Wine growers are increasingly faced with a trade-off of having to accept the impacts of severe water shortages or irrigate to overcome serious problems resulting from decreased crop yields and harvest quality.

Recent scientific advances have made it possible to propose wine growers sustainable irrigation models based on control of the water status—the key element determining the physiological function of grapevines relative to production goals. This approach addresses a tangible demand coming from most of the European wine sector. These vineyard water status control models, developed by UE Pech Rouge, generate information on the effects of water stress (depending on the extent) on grape and wine yield and quality, and on optimal thresholds for grapevines according to the phenological stage. Commercial vineyard irrigation strategies can be managed on this basis according to targets, while being tailored to the specific features of each *terroir*.

In areas where irrigation is not crucial (most European vineyards), the water status is controlled to a limited extent via tillage and vineyard management. In such cases, the vineyard water status (available soil water) is a major factor in explaining the *terroir* variability concept. In areas with low rainfall and where irrigation is therefore essential for vine crops, in areas with heavy droughts, as is the case in most 'New World' wine producing countries, or in areas with occasional heavy droughts, it is important to have a precise idea of the responses of grapevines to the water status so as to be able to choose the best irrigation strategies to adopt according to the production targets.

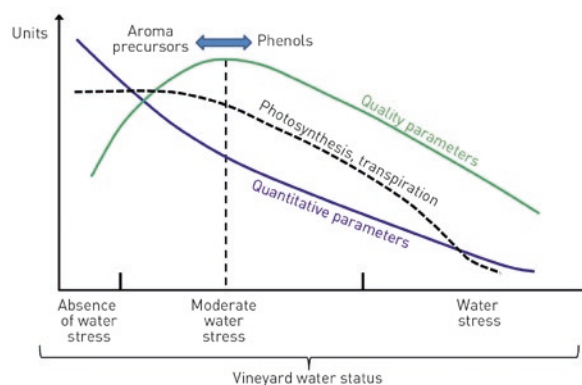
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Different possible irrigation strategies to control the vineyard water status according to the vegetative period and type of targeted product: [A] concentrated musts, grape juice, table wines and young vineyards being set up; [B] white wines, light fruity red wines; [C] young quality wines, balanced but with fruit predominating in the structure, limited thresholds for white wines, and [D] quality wines, concentrated, balanced and suitable for ageing [Ojeda & Saurin, 2014]

<sup>1</sup> baseline water potential ( $\Psi_b$ ), peak stem potential ( $\Psi_t$ ), peak leaf potential ( $\Psi_l$ )



Influence of the water status on vineyard qualitative, quantitative and physiological parameters.

### ▲ Methods, tools and strategies to maximize the grape harvest quality and yield while saving water

© From Ojeda H., Saurin N. 2014. *Innovations Agronomiques* 38/97-108



▲ Programme stakeholders visiting an irrigated vineyard plot  
© F. Etchebarne/INRA



▲ Drip irrigation  
© Aquadoc

## Vineyard irrigation management support

The water use issue in vineyards is becoming highly critical since soil evaporation and plant transpiration are increasing with climate change. Irrigation is thus being used to a greater extent and the limits imposed by regulations are rapidly changing. However, due to the negative impacts of excessive irrigation on production and to the growing competition with industrial and domestic water uses, it is essential to gain further insight into the optimum required to meet harvest goals in terms of both quantity and quality.

The joint research unit LEPSE, associated with other Agropolis research teams (UMR Eco&Sols\*) and a private partner (ITK company), have contributed to the development of a software tool to assess daily water consumption in vineyards and the soil water status. One difficulty was to estimate the quantity of water accessible to roots in often complex soils and tapped by roots remotely located from the vine stump. By combining soil characteristics, climatic conditions, direct observations of soil root development and physiological measurements obtained at key stages of vine plant development, a mathematical model was built to predict the soil water status during the vine growth cycle. The model gave rise to a software package that can be used to determine potential irrigation water quantities required according to a climate scenario and production goals.

\*UMR Functional Ecology & Bio-geochemistry of Soils and Agro-ecosystems (INRA, IRD, Montpellier SupAgro, CIRAD)

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▲ Measuring the transpiration flux of a vine plant using a sap flow sensor

This type of sensor is used to acquire experimental data that can be used to test simulation model performance. (a) setting up the sensor (b) installed sensor.

© INRA/LEPSE



▲ Monitoring the vineyard water status by measuring the leaf water potential and stem water potential

These measurements are obtained in a pressure chamber.

© INRA/LEPSE



▲ Graphic interface of the ITK-Vigne irrigation management tool

© INRA/LEPSE

# Sustainable vitiviniculture

## Wine cropping systems with low pesticide inputs

DEPHY—a network for demonstration, experimentation and the production of references on low pesticide cropping systems—is a major initiative of the French *Plan Écophyto*. This network aims to develop, pool and disseminate examples of cropping systems that markedly reduce pesticide use. Low pesticide input and economically efficient cropping systems (SCEP) have thus been identified. In this framework, the SCEP-DEPHY project proposes to use databases created by network engineers (mainly chambers of agriculture) that manage the DEPHY national demonstration farm network.

This database describes wine cropping systems in various French regions. The project aims to extract knowledge on low pesticide cropping systems. The plan to achieve this includes: (1) characterizing and identifying cropping systems that are economic, with respect to pesticide inputs, while also performing well (grape yields and quality), called E&P, (2) identifying combinations of factors that promote the E&P features of wine producing systems (geography, soils, types of wines produced, etc.), and (3) conducting multicriteria assessments,

while incorporating other aspects regarding the sustainability of these cropping systems (via various tools such as lifecycle analysis, DXiPM or INDIGO models).

This project is focused on field crops, arboriculture, viticulture and vegetable crops. The 'viticulture' component is coordinated by UMRs Innovation and SYSTEM. It involves collaboration with experts in the concerned sectors, multicriteria assessment specialists and agricultural statisticians.

The SCEP-DEPHY project, coordinated by UMR Agroecology (INRA Dijon), is the result of the research proposal call 'For and on the *Plan Ecophyto 2018*', following the 2012 proposal 'For and on three components of the *Plan*: epidemiological surveillance, DEPHY farm networks and assessment indicators'.

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## Improved management of pest control interventions – from decision making to controlled treatments

### Mildium©: an operational decision-making process for fungicide treatments

The National Research Institute of Science and Technology for Environment and Agriculture (IRSTEA) has cooperated with INRA Bordeaux pathologists to model a viticulture fungicide crop protection decision-making process called Mildium©. The 'decision-making process' refers to decisions to make according to temporal dynamics, such as vine growth, meteorological patterns and associated bioclimatic risk indices. The Mildium© process, which concerns mildew and powdery mildew affecting grapevines, involves field observations at specific stages. It has been tested, in partnership, on many plots in Atlantic coastal, southern and northern regions of France. Published results show, on the plot scale, the possibilities of reducing the treatment frequency index by 30-50%. Mildium© is also designed to promote apprenticeship, which enables the treatment strategy to be tailored to specific farm objectives and production conditions.

### Innovative tools for characterizing and optimizing pesticide spraying

IRSTEA (UMR ITAP) has developed, as part of the LIFE AWARE (2005-2009) and TICSAD (2006-2010)\* projects, a system for displaying, recording and achieving the traceability of pesticide treatment parameters. This provides farmers with a tool to help them manage and optimize crop protection treatments (up to 15% reduction). They can monitor spraying operations in real time, while saving time and enhancing precision during the preparation and treatment phases. This project led to the development of the PICORE system, which has been promoted by the company SIKA GmbH and was presented at SITEVI 2015. This system uses ICT technologies (GSM mobile phones and WiFi) to convey automatic instructions and specifications for plots via a webserver; a portable measuring device and a smartphone HMI display. In the future, a portable light detection and ranging (LIDAR) laser remote sensing system could be used to characterize vegetation studied at IRSTEA (UMT ECOTECH-VITI) so as to be able to tailor pesticide dosages to the vegetative stages of the crop.

\* LIFE AWARE project: Reducing pesticide-related water pollution by improving crop protection practices; the use of embedded ICT technologies. TICSAD project: ICTs for sustainable agriculture.



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## Panoramix project – can wine growers adopt pathogen-resistant grapevine varieties?

The Panoramix project involves INRA laboratories in Bordeaux, Paris, Colmar and Montpellier, focused on studying the genetic, biological, agricultural and socioeconomic conditions regarding the development of disease-resistant grapevine varieties. In Montpellier, UMR Innovation conducted (in Languedoc-Roussillon region) an in-depth sociological study on the conditions of appropriation of conventional European hybridized mildew and powdery *Vitis vinifera* varieties and American or Asian wild varieties bearing monogenic or polygenic resistance. The social trajectory regarding the innovation of these resistant varieties was characterized via interviews with stakeholders (researchers, engineers, experimenter wine growers, etc.), by explaining the current scientific or professional controversies, but also by identifying the potential and specific requirements for adoption by the wine sector.

Wine growers have high expectations because of growing concerns on pesticide treatments, but there are still few guarantees for the development of resistant vine varieties due to the lack of subsidies, the need for further information and advice, a facilitated

administrative framework, more complete assessment of the qualities and commercial prospects, etc. Studies aimed at facilitating the dissemination and appropriation of resistant varieties have identified facilitating political, economic, support and communication conditions.

The development scenarios will necessarily be progressive. Resistant vine varieties must be tailored to the needs of a range of wine growers and could be the focus of complementary production and marketing strategies. Research is under way to strengthen the resistance and qualitative profiles of varieties, but it is essential to establish an enabling environment to ensure wider innovation adoption.

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[www6.inra.fr/ciag/CIAG-Agriculture/Viticulture-et-stress-hydrique](http://www6.inra.fr/ciag/CIAG-Agriculture/Viticulture-et-stress-hydrique)

## Assessment of a soil conservation strategy for viticulture landscapes

Soil degradation is largely due to inappropriate land-use and cultivation practices, and this situation is likely to worsen in the future due to rapid changes in Mediterranean vineyard landscapes (climate, anthropogenic and socioeconomic changes). These changes will ultimately lead to changes in land-use patterns and practices prompted by farmers and decision makers as an adaptation strategy.

The aim of this study—carried out by UMR LISAH in collaboration with other French laboratories in the framework of the ANR LandSoil project—was to compare the effects of different landscape change scenarios (land use and spatial patterns) on the evolution of soil resources. The final objective was to contribute to developing good soil and vineyard landscape management practices. The LandSoil digital model was thus created and used for foresight simulations (see figure below). Degradation involving soil loss via different erosion processes (water and tillage) was taken into account.

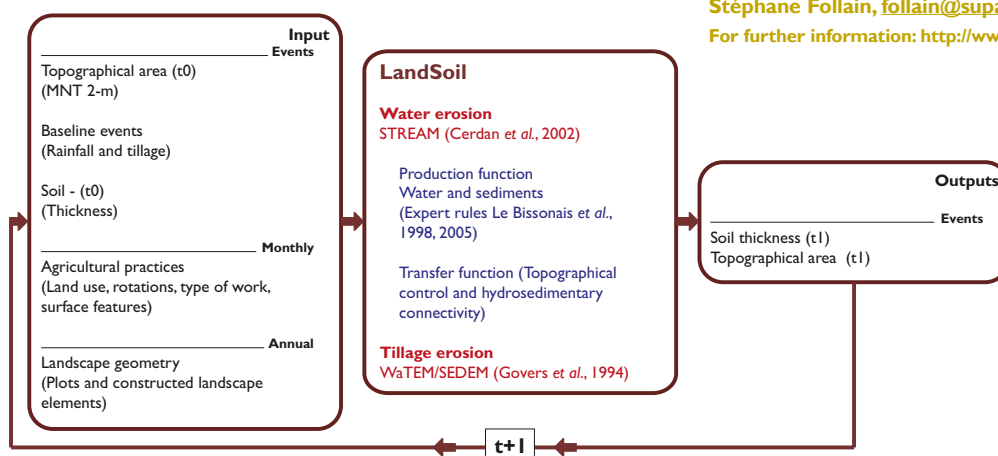
In a Mediterranean wine growing setting, the analysis of overall results for a 100-year period highlighted that inappropriate land use led to higher soil loss than noted with supposedly intensive vineyard spatial patterns (large plots, rows oriented according to the greatest slope, etc.), and 12-fold greater than simulated in a stationary scenario (no changes in conditions as compared to the current situation). The land degradation potential is higher than the conservation potential under these conditions. The analysis of land redistribution due to erosion confirmed the importance of land use in managing erosion processes and reaffirmed the importance of landscape structuring (plot spatial patterns), which promotes or not the storage of volumes of eroded soil on slopes.

The development of soil conservation strategies should thus focus on land use and practices that reduce land susceptibility to erosion so as to ensure effective soil conservation. When this lever is not possible, another key alternative lever is to spatially restructure the landscape to promote the storage of volumes of eroded soil on slopes.

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▲ Presentation of the LandSoil model © UMR LISAH

## Weed cover and soil fertility management in vineyard systems

UMR SYSTEM is involved in the European EraNet FertCrop project\* (2015-2017) which aims to assess and enhance soil fertility for different European cropping systems.

The first research focus concerns the analysis of weed dynamics in vineyard plots in response to soil maintenance strategies (tillage or sown grass cover) and the impacts on interrow fertility. The unit is thus developing models on soil nitrogen balances in vineyard systems with weed cover and is identifying soil and plant cover indicators with the aim of: (1) assessing the level of competition for soil resources generated by weed cover; and (2) controlling the management of topsoil in order to enhance control of soil resource availability and grapevine yields.

The second focus concerns the development of an integrated approach for assessment and development of soil surface management strategies in organic viticulture.

Specific attention will be paid to the dynamics of these weed cover processes in farmers' plots during the organic farming conversion period.

Moreover, soil management strategies will be developed to optimize soil surface management and to better control soil biological properties and crop growth and yield. Finally 'soil' and 'plant' indicators will be used in decision-making rules that could be assessed in research stations and vineyards.

\* EraNet (European Research Area Network) FertCrop (Fertility Building Management Measures in Organic Cropping Systems) project.



▲ Soil management combining tillage along the rows and weed management in the interrows in a Domaine du Chapitre vineyard plot

© Y. Bouisson/UMR SYSTEM

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## EvaSprayViti – an artificial vine for agroenvironmental optimization of vine crop spraying



▲ Testing a side-by-side sprayer on an EvaSprayViti test bench

© IFV/IRSTEA

EvaSprayViti tool is an adjustable artificial vine that enables objective and replicable measurements of the spraying quality, with testing under controlled conditions of the performances of different spraying equipment and practices. This test bench reproduces four 10-m long vine rows. Three different bench configurations correspond to three vine development stages (beginning, middle and full vegetation), so sprayers and spraying practices can thus be tested according to the vine vegetation pattern.

Initial results have confirmed that spraying optimization and precision spraying are key ways to reduce pesticide use. They also raise the question as to the harmonization of ways of expressing spray dosages in Europe. In France, for instance, dosages are expressed per cadastral hectare, whereas in other European countries they differ according to the vine vegetative development stage.

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**For further information: see the video presenting the tool on: [www.youtube.com](http://www.youtube.com)**



# Diversification of grapevine products

## Development of a specific grape juice sector

The experimental FIJUS-R@ISOL research programme\* (2008-2015) was aimed at developing a range of pure grape juices with improved nutritional value and setting up a specific grape juice sector. This involves answering questions and defining specifications necessary for the adaptation of such a sector using grapevine varieties devoted solely to grape juice production (not wine). Cropping methods and process have thus been revised from a reverse engineering standpoint, i.e. from the bottle to the plot.

The study—scientifically coordinated by INRA Pech Rouge—led to the selection of 14 new grape juice specific varieties from 448 genotypes and according to the industrial interest. Ten of these varieties, nine hybrids and a *Vitis vinifera* variety will be registered in the viticulture catalogue in late 2016. The next step is to boost the production potential to over a million hectolitres, to reduce the sugar/acid ratio to close to that of apple juice. The specifications have thus been defined on the basis of the following criteria:

- high yield (over 150 hl/ha for red grape varieties and, if possible, 250-300 hl/ha for high yielding white grape varieties)
- low sugar content (around 120 g/l)
- acidity of over 7 g/l (equivalent to sulfuric acid), pH in the 2.8-3.2 range
- high polyphenol content for red grape juice (total polyphenol indices of over 3 g/l)
- aromatic
- good or quite good fungal disease resistance
- good agricultural performance.

The selected varieties will also meet, in a more environment-friendly way, organic agriculture requirements. Three other INRA-bred varieties are still being studied for their fungal disease resistance. They have nevertheless been preselected because of their excellent quality levels, including aromatic qualities.

The project involved many public and private sector partners\*\*, while being co-accredited by the Qualiméditerranée and Vitagora competitive clusters.

\* Funding: FUI, BPI France, France AgriMer, *Conseil régional Languedoc-Roussillon*

\*\* Project led by the company Foulon-Sopagly, Europe's leading grape juice producer. The partners are INRA (UEPR, *Domaine de Vassal*, UMR SPO, UMR AGAP), IFV ENTAV, UMT Géo-Vigne, ICV, wine cellars SAS Roquecourbe, SCA Vignoble de la voie Héraclès, Institut de santé STIC Dijon.

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### ► Preparation of grape juice samples (2014 vintage) for colour analysis

© M.Veyret/INRA Pech Rouge



## Materials developed with tannins – a new market for the wine industry?

Plastic materials and most medicines are currently produced by the petrochemical industry, i.e. made from petroleum-based chemical compounds. In one century, however, the extraction and use of petroleum as a main energy source has led to almost total depletion of the reserves that had formed over millions of years. Finding ways to produce energy and chemical compounds based on renewable resources such as plants or (more generally) biomass, is a key challenge. The use of wastes as raw materials is part of the circular economy concept that our society is striving to adopt.

In the wine sector, the biorefinery principle is not really new, as illustrated by distilleries in charge of 'eliminating' wine by-products. In addition to alcohol production, distilleries have innovated and diversified products derived from marc development. Polyphenols are very widespread in the plant kingdom. From a chemical standpoint, they are close to phenol and petrochemical-based derivatives which are used massively in the industry for specialty chemicals or for the synthesis of plastic materials. Substitutions are therefore possible.

Studies carried out by UMR SPO in collaboration with other Montpellier-based teams (*Institut Charles Gerhardt* and UMR Agropolymer Engineering and Emerging Technologies) have begun

substituting bisphenol A in epoxy resin synthesis. After 6 years of research, three patents have been deposited concerning the use of organic sources of polyphenols to produce platform molecules that could be functionalized for specialty chemicals or used as building blocks for making polymers and resins. Polyphenols are not targeted and any waste or biomass materials with a high polyphenol content could be used in this process. The diverse range of natural structures have the advantage of conferring properties that are flexible and sometimes specific.

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### ▲ Epoxy resins produced with seed-extracted tannins from marc

The colour is associated with the degree of epoxy prepolymer purification.

© É. Dubreucq/UMR IATE



# Partnerships and innovations to support businesses

**A**gropolis International member research teams working on viticulture and wine have close partnership relationships with other public research teams, and with economic stakeholders. This platform functions on local, national and international levels.

Locally, the research teams are mainly involved with companies of the *Qualiméditerranée* competitive cluster\* and the *Vinseo* cluster\*\*.

The partnerships often lead to innovation transfers which strengthen the competitiveness of the partner businesses. The teams are also involved in joint projects with chambers of agriculture, unions and interprofessional organizations. This investment with local stakeholders facilitates meeting their expectations, incorporating their practical knowledge, while better anticipating the challenges of the sector. The Languedoc wine region has a highly diverse range of wines, *terroirs* and projects, so the results are transferable to other wine regions.

Nationally, the scientific platform is integrated in national innovation strategies coordinated by INRA, IFV and IRSTEA. This enhances the distribution of work between geographical centres and setting up of trials on various technologies under different geographical and production conditions. The platform—because of the diversity of wine estates in the region and the Mediterranean climatic conditions—is a forerunner in climate change adaptation research.

Internationally, exchanges with other global public and private viticulture and wine research leaders enable the transfer of data, practices, staff and material, especially plants, to enhance local scientific research. The marked presence of Agropolis International member teams in OIV commissions and expert groups substantiates the relevance of their scientific position on the international stage.

The scope of the viticulture- and wine-oriented scientific platform and the excellent partnerships established have given rise to major innovation themes, through:

- the definition of ideotypes, which has led to the breeding of varieties that combine disease resistance and compliance with typicity
- the development of tools to control water supplies, or the use of new sources such as treated water
- the design and development of vineyard and winemaking equipment using tools that facilitate tasks ranging from defining concepts to their validation on a real scale in wine estates
- the development of wine yeasts that meet professional winemakers' demand via innovative selection methods
- the use of new extraction methods to make effective use of coproducts or to create new inputs
- the support for strategic development of the sector through co-construction, prospective or corporate social responsibility approaches, but also via projects focused more on corporate strategies (feasibility studies, marketing geared towards new consumer targets, etc.)
- the transition to precision viticulture by making effective use of the many possibilities offered by the digital revolution: development of tools (probes, decision-support tools, etc.), provision of heterogeneous and multi-source data integration methods, use of spatiotemporal data and the development of methods for the analysis of high volumes of data collected in vineyards, wineries and distribution channels.

## Institutional partnership services

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### French Institute for Vine and Wine (IFV)

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[www.vignevin.com/ifv-services/presentation-difv-services.html](http://www.vignevin.com/ifv-services/presentation-difv-services.html)

These innovations can be combined to come up with solutions to major socioeconomic issues, such as adaptation to climate change, development of sustainable viticulture or the quest for new opportunities.

To accelerate such transfers, all institutions of the Agropolis scientific community have a partnership service (see below). The aim of these services is to facilitate business access to research laboratories and they fulfil three main tasks: (1) negotiation, appraisal and management of partnership research contracts, (2) the development of service provision, and (3) company transfer of results to wine estates. Some teams have also developed a business start-up support service.

Partnership research contracts with other public or private institutions require joint preliminary definition of the objectives and methods necessary to obtain solutions to specific problems. The results can lead to various deliverables: patents, software, databases, varieties, secret know-how, dissemination of methods, etc. In addition, Montpellier SupAgro and INRA have set up an incubator to host project leaders and support them via the SYNERSUD network<sup>\*\*\*</sup>. In 2015, seven projects on viticulture and wine were hosted by this incubator. IRSTEA also has an incubation site that can host businesses monitored by the regional incubator—Languedoc Roussillon Incubation (LRI)<sup>\*\*\*\*</sup>.

Alongside the research, most experimental and technical platforms managed by research teams offer businesses and public organizations services based on completely controlled protocols (mini-vinification, fine chemical analysis of polyphenols, aromas, etc., standardized sensory analyses, ICT assessments, etc.). These services usually help to check specific aspects of processes (e.g. does a yeast enable high quality vinification?) or to measure a new data result, e.g. the quantity of polyphenols in a product, etc. They can also raise new research issues and open novel innovation perspectives.

\* Competitive cluster devoted to sustainable agrotechnologies, [www.qualimediterranee.fr](http://www.qualimediterranee.fr)

\*\* Network of suppliers of the South of France wine sector: [www.vinseo.com](http://www.vinseo.com)

\*\*\* Languedoc-Roussillon-based network devoted to supporting and creating innovative businesses: [www.synersud.com](http://www.synersud.com)

\*\*\*\* [www.lr-incubation.com/en\\_presentation.php](http://www.lr-incubation.com/en_presentation.php)

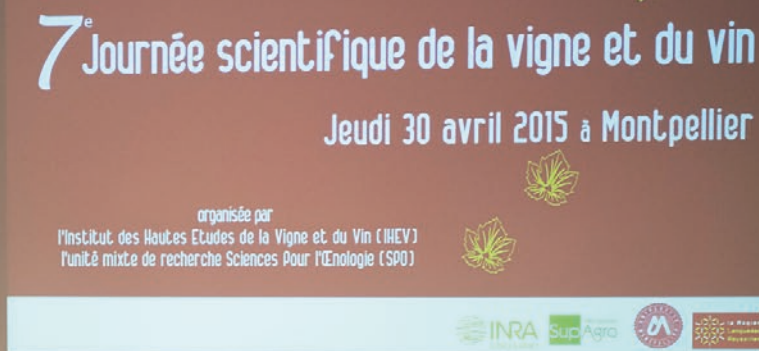


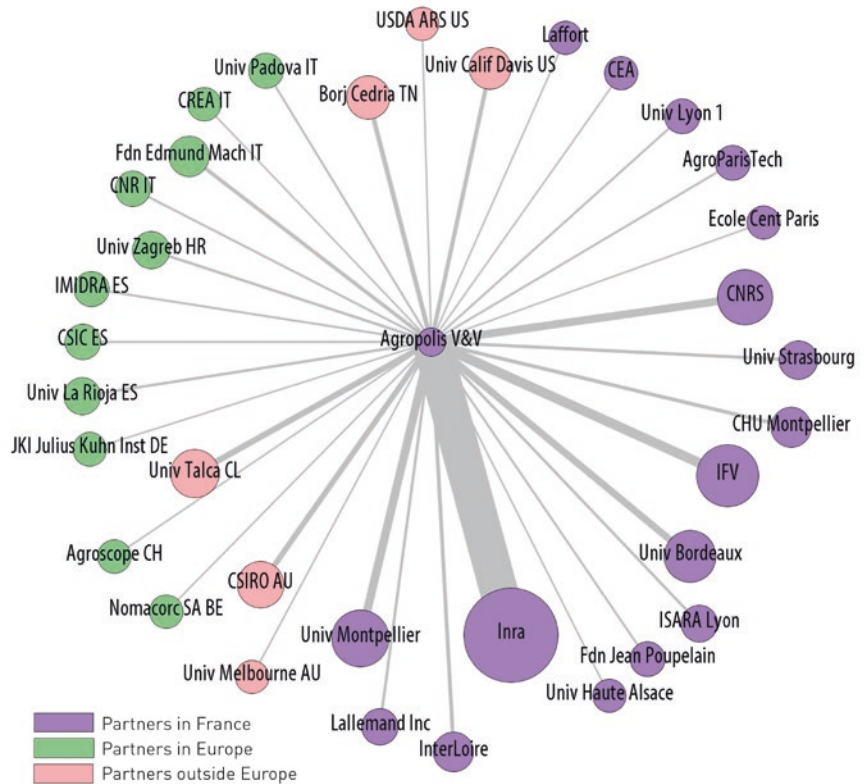
▲ Signature of a partnership agreement with Vinseo—a network of wine sector suppliers

© Service Communication - Montpellier SupAgro

▼ A presentation on recent research advances and potential applications of results at the Journées scientifiques de la vigne et du vin—a yearly seminar for stakeholders in the viticulture and wine sector

© G. Bouteillier





► The main French and foreign partners with which the Agropolis International scientific community published at least four documents between 2008 and 2014 (network diagram designed using Gephi with WoSTM Thomson Reuters data). © D. Fournier/INRA

## Strategic foresight – what viticulture and wines for tomorrow?

Can we predict the future? Certainly not! But can we foresee or contribute to its construction? Strategic foresight was introduced in the viticulture and wine sphere via an initiative of the *École d’Agronomie de Montpellier* in 1998 with the aim of assessing the major changes under way in the sector—technical, economic and social—and foreseeing the impacts, especially for research and education. A national foresight study was then carried out by INRA\* (2003). Since then, FranceAgriMer has created a unit devoted to strategic foresight and a partnership was established which regularly associates its foresight experts with those of Montpellier for studies focused on the viticulture and wine sector.

Since 2004, these foresight research specialists have regularly called upon experts from the Montpellier platform to meet requests from various professional organizations (unions, interprofessional organizations, etc.), businesses (consortium of input suppliers, cooperatives, multinational corporations, etc.) and public authorities.

In 2011 and 2012, a study led by Montpellier SupAgro/IHEV and INRA, at the request of the Regional Directorate for Agriculture, Agrifood and Forests (DRAAF) in Languedoc-Roussillon (FranceAgriMer funding), resulted in the building of regional scenarios on the future of viticulture in Languedoc region for 2025, in relation to territorial patterns (demographic, water supplies, etc.), while bringing together professional stakeholders in a pluralistic viticulture setting (see below).

### Strategic foresight of Buzet winemakers

‘Scoping future opportunities and controlling our destiny through strategic foresight’. This could characterize the approach of the *Vignerons de Buzet* cooperative which has opted to build its strategy on the basis of an in-depth foresight study carried out by Montpellier SupAgro/IHEV in which all of its executive and administrative senior staff were involved over a 3-year period. This was followed by a strategic foresight initiative and drawing up of a strategic action plan (2011), which has since then given rise to periodic gap analysis seminars. This approach is fully in line with the cooperative’s early, shared, exemplary and unflinching commitment to sustainable development.

For further information: [www.vigneronsbuzet-durable.fr/en](http://www.vigneronsbuzet-durable.fr/en)

Finally, as foresight research is interdisciplinary, the methods are commonly used to facilitate and provide resources to promote transdisciplinarity between workshops in large-scale research projects, such as the 2005–2008 ANR project ‘Low-alcohol quality wines’ and, since 2013, the LACCAVE climate change project.

\*Study headed by Michel Sebillotte and coordinated by Patrick Aigrain (FranceAgriMer), Hervé Hannin (Montpellier SupAgro-IHEV) and Clementina Sebillotte (INRA).

#### Overview of four viticulture scenarios in Languedoc-Roussillon region for 2025

|  |  |
|--|--|
| <p style="text-align: center;"><b>1</b></p> <p style="text-align: center;"><b>PLURALISTIC SECTOR</b></p> <ul style="list-style-type: none"> <li>→ Pluralistic viticulture organized</li> <li>→ ‘Together we stand’</li> <li>→ Area: 230 000 ha</li> <li>→ Volume produced: 13-15 million hl</li> </ul>     | <p style="text-align: center;"><b>2</b></p> <p style="text-align: center;"><b>LANDSCAPE SECTOR</b></p> <ul style="list-style-type: none"> <li>→ Oenotourism</li> <li>→ ‘Those who stay make a decent living’</li> <li>→ Area: 180 000 ha</li> <li>→ Volume produced: 10-12 million hl</li> </ul>                       |
| <p style="text-align: center;"><b>3</b></p> <p style="text-align: center;"><b>DECLINING SECTOR</b></p> <ul style="list-style-type: none"> <li>→ Soulless organization without projects</li> <li>→ ‘Missed opportunities’</li> <li>→ Area: 150 000 ha</li> <li>→ Volume produced: 7-9 million hl</li> </ul> | <p style="text-align: center;"><b>4</b></p> <p style="text-align: center;"><b>LIBERAL SECTOR</b></p> <ul style="list-style-type: none"> <li>→ Selective industrial development</li> <li>→ ‘Everyone for themselves — some succeed’</li> <li>→ Area: 180 000 ha</li> <li>→ Volume produced: 10-12 million hl</li> </ul> |



▲ Strategic foresight meeting at Montpellier SupAgro/IHEV for the *Vignerons de Buzet* cooperative, with the managing director Pierre Philippe, and the presidents Serge Lherisson and Vincent Leyre © *Vignerons de Buzet*



▲ Entrance to the Faculty of Pharmacy at the Université de Montpellier © UM



▲ Teacher and students during a physicochemical analysis workshop © Montpellier SupAgro



▲ Montpellier SupAgro Campus, esplanade in front of the main entrance © M. Calleja/Montpellier SupAgro-IHEV

# Training offered by Agropolis International member institutions in the viticulture and wine field

**U**niversities and engineering schools (as well as vocational training institutions) that are Agropolis International members propose a complete training-education programme.

The training-education programme includes more than 80 diploma courses (from Bac +2 to Bac +8: technician, engineering degree, Master's, PhD), as well as vocational training modules (existing or developed upon request).

The table below outlines the training-education courses related to the viticulture and wine domain. It specifies the diploma levels, a description of the training and the institutions where the training is provided.

| Level   | Degree  | Title  | Institution   |
|---|---|--|---|
| Bac + 5   | <i>Ingénieur</i><br>(Engineering degree)                    | <b>Agricultural engineering</b><br>Specialization 'Viticulture-oenology'   | Montpellier SupAgro-IHEV  |
|   | DNCE  | <b>National Oenology Diploma</b>   | Montpellier SupAgro-IHEV  |
|   | DNCE  | <b>National Oenology Diploma</b>   | UM  |
|   | Master<br>(MSc)   | <b>Agronomy and agrifood science</b><br>Specialization 'Viticulture, oenology, economics and vitivinicultural management'<br>Emphasis 'Viticulture and wine' | Montpellier SupAgro-IHEV<br>Bordeaux Sciences Agro                    |
|   |   | <b>Vinifera EuroMaster</b><br>International Master in Vine and Wine Sciences<br>Erasmus Mundus + In partnership with seven European universities             | Montpellier SupAgro-IHEV<br>consortium européen EMaVE                 |
|   | Master 2<br>(MSc)   | <b>Distinction 'Marketing and sales'</b><br>Emphasis 'Wine marketing'  | UM et Montpellier SupAgro-IHEV  |
|   | DES / OIV-MSc   | <b>Secondary school diploma (DES) in viticulture and wine management</b><br><b>OIV Master of science in wine management</b>                                  | Montpellier SupAgro and OIV   |
|   | Master Grande École<br>(Business school<br>MSc)             | <b>Specialization 'Trade and Sales'</b><br>International Wine Marketing Certificate  | Montpellier Business School   |
| Bac + 3   | Licence<br>(BSc)  | <b>Chemistry</b><br>Emphasis 'Preparation of the National Oenology Diploma'  | UM  |
|   | Licence professionnelle<br>(BSc with<br>professional scope) | <b>Legal activities</b><br>Specialization 'Law and management of the vitiviniculture sector'   | UPVD at Narbonne  |
|   |   | <b>Management of quality systems for the vitiviniculture sector</b>  | Montpellier SupAgro-IHEV, EPLEFPA Orange,<br>Aix-Marseille Université |
|   |   | <b>Sales manager for wine and distribution networks</b>  | EPLEFPA Montpellier-Orb-Hérault,<br>Montpellier SupAgro-IHEV, UM      |
|   |   | <b>Wine tourism and cultural project</b>   | Université de Nîmes<br>Lycée agricole de Nîmes Rodilhan               |
| <b>Integrated viticulture and environmental certification</b> | Montpellier SupAgro, UPVM3<br>CFPPA Bordeaux, CFPPA Beauce  |  |   |
| Bac + 2   | BTS<br>(Advanced<br>vocational training<br>certificate)     | <b>Sales representative 'Drinks, wine, spirits'</b>  | Lycée Frédéric Bazille-Agropolis Montpellier                          |
|   |   | <b>Viticulture-Oenology</b>  |   |

## AGRICULTURAL ENGINEERING DEGREE, SPECIALIZATION 'VITICULTURE-OENOLOGY', MSC 'VITICULTURE-WINE' AND NATIONAL OENOLOGY DIPLOMA (DNCE)

**Agricultural engineering degree, specialization 'viticulture and oenology'**, historical training in the field of viticulture and wine at the Bac + 5 level, this programme meets the national and international demand for high level scientific and technical staff to support the modernization of the viticulture and wine sector in many wine-growing countries. Graduates have multidisciplinary scientific and technical knowledge enabling them to adapt to changes in global markets and in the global vitiviniculture sector.



▲ DNCE students during a sensorial analysis session

© Montpellier SupAgro-IHEV

**National MSc in viticulture and wine** an MSc programme in the science and technology field, distinction 'agriculture and agrifood science' (3A), specialization 'viticulture, oenology, economics and vitiviniculture management', is jointly organized by Montpellier SupAgro and Bordeaux Sciences Agro. Graduates are prepared for implementing viticulture and oenology techniques, defining production strategies and crop management interventions in relation to marketing, while conducting experimental research projects to address sectoral development needs worldwide. This training (offered in French) is for foreign students and vocational training students, or candidates with a BSc degree, or equivalent, in scientific disciplines.

## National Oenology Diploma (DNCE)

This European Higher Education Area oenology training programme, at the MSc (Bac +5) level, is recognized by OIV.

Graduate oenologists must have sufficient technical, legal and economic knowledge for winemaking in accordance with composition and quality standards. This knowledge ensures that graduates are wine experts and guarantors of winemaking and control procedures. They have a role in preserving consumers' health and the quality of the environment.

The National Oenology Diploma (DNCE) is awarded by Montpellier SupAgro within the framework of the curriculum at IHEV and the *Université de Montpellier* (UM) through its Faculty of Pharmacy. The admission and course organization conditions differ at IHEV and UM.

At Montpellier SupAgro, students generally follow the DNCE programme in parallel with the agricultural engineering curriculum, specialization 'viticulture-oenology', or the MSc 'viticulture-wine' curriculum, and they thus obtain a joint degree.

At UM, the DNCE programme is organized by the *Centre de formation et de recherche œnologie* (CFROE) within the UM Faculty of Pharmacy. This Centre is also supported by the *Fondation de l'Université de Montpellier* via the OENOFUTUR research and education chair. Several activities are organized, including conferences for students and professional operators in the sector. This training addresses all aspects of grape cropping (viticulture) and winemaking (oenology) occupations, including economic, marketing and legislative aspects. It is geared towards young BSc (or equivalent) graduates in scientific disciplines and vocational training staff. The courses are provided by both teachers-researchers and external professional specialists in these fields.

## OTHER MSC PROGRAMMES RELATED TO THE VITICULTURE AND WINE THEME

### Vinifera EuroMaster

Vinifera EuroMaster is an international Master's programme in vine and wine sciences that is jointly offered by partners of the EMaVE consortium, whose founding members are Montpellier SupAgro and Bordeaux Sciences Agro (France) and agriculture universities of Madrid (Spain), Lisbon (Portugal), Turin (Italy), Udine (Italy) and Geisenheim (Germany).

This course—created in 2006 and supported by the *Erasmus Mundus* label since 2008 and the UNESCO Chair *Cultures et Tradition du Vin* since 2011—trains high level international staff to obtain multidisciplinary expertise that they can use to support the development and modernization of the vine and wine sector worldwide.

Applicants must have an international profile, speak three languages and have obtained a BSc degree in biology or agricultural science and technology. Only around 30 students a year are admitted to this programme out of some 300 applicants!

The programme, coordinated by Montpellier SupAgro through IHEV, includes a first year (M1) in France, in Montpellier for 8 months and in Bordeaux for 1 month, with all courses offered in English. In the second year (M2), students attend the course in European universities that are members of the EMaVE consortium, with their final end-of-course project conducted in one of the partner universities, especially in the Southern Hemisphere.

Since its launch, this training programme has continued to innovate on an educational level, especially with the creation of two new e-learning modules, 'Research Project' and 'Professional Immersion', thus enhancing the balance with the number of classroom courses. A MOOC\* is in preparation as an online refresher for certain students.

So far, 200 Vinifera EuroMaster graduates are working worldwide, with careers in different viticulture and wine sectors, in companies—import-export or as winemakers in prestigious wine estates—in professional organizations, in teaching or research (postdoctoral). Every year, about 30 students, from nearly 20 nationalities, participate in this innovative and efficient training programme.

\*MOOC = massive open online course



▲ First day of classes for the ninth contingent of the Vinifera EuroMaster programme © Montpellier SupAgro-IHEV



▲ DNCE programme at the Université de Montpellier-Faculté de Pharmacie-First day of classes 2015 © C. Saucier



## OIV MSc in wine management

OIV MSc in wine management is a Master's (Bac+5) degree that was created in 1986 at the initiative of OIV. This MSc programme, jointly offered by Montpellier SupAgro and OIV, is organized by the *Association Universitaire Internationale du Vin*. It prepares students on managerial decision making in the viticulture and wine sector (marketing, management, economics, law, human resources, communication). Students are registered at Montpellier SupAgro-IHEV and receive a specialized studies degree (MSc level; Bac+5). The training (in English and French) lasts 16 months in 22 countries. It is organized in 28 modules, with each being devoted to a specific topic and a studied and visited host region (transnational experiential education). For each module, a university or professional centre serves as the organizer. This multidisciplinary mobile training gives future decision makers a complete overview and immersion in the global wine sector.

This Master's programme is unique in that it favours studies requiring a high level of commitment and autonomy from participants. Another unique feature is that students discover situations regarding markets and sectoral stakeholders directly in their international setting on five continents, and the programme is officially recognized by OIV.

The training involves a balanced alternation of case studies of companies, meetings with professional operators (over 500 a year) and classroom teaching. The teachers include university professors and researchers specialized in the sector, and also

professional business representatives with recognized experience in their field—sales managers, marketing specialists, producers, legal experts, etc. Twenty-six classes have already been trained, representing a solidary network of over 450 graduates from around 40 nationalities.

The programme is suitable for anyone who has successfully completed 4 years of university studies and is motivated by a professional project specifically oriented towards viticulture and wine occupations. A good command of French and English is essential.

## Master's 2 'Wine marketing'

The Master's 2 'Wine marketing' training programme is jointly coordinated by UM and Montpellier SupAgro. The aim is to train commercial staff specialized in the vitiviniculture sector, with a high level of commercial marketing, negotiation and management based expertise.

This Master's programme has a clear 'professionalization' focus as students can attend training classes under a professional or apprenticeship contract. The international scope is reflected by the proportion of classes offered in English, training courses abroad and the involvement of international students. The courses are given by teachers-researchers from UM and Montpellier SupAgro, as well as by external professional specialists recognized in the viticulture and wine field. This MSc programme is supported by a network of businesses, institutions and professional organizations that foster professional integration.



▲ Grape picking in an experimental vineyard during the MSc2 'Wine marketing' integration session

© Montpellier SupAgro-IHEV



▲ An on-campus contingent of students of the OIV MSc in wine management programme with J.M. Aurand, D.G. of OIV, A.-L. Wack, D.G. of Montpellier SupAgro and the AUIV managers

© Montpellier SupAgro

Recruitment is aimed at young graduates who have obtained a Master's 1 degree in economics, management, linguistics or agricultural science, or who have an equivalent degree from a foreign university.

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**BSc with professional scope – Integrated viticulture and environmental certification**  
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# List of acronyms and abbreviations

|                  |  |
|------------------|--|
| <b>ADEME</b>     | French Environment and Energy Management Agency / <i>Agence de l'environnement et de la maîtrise de l'énergie</i>  |
| <b>ANR</b>       | French National Research Agency / <i>Agence nationale de la recherche</i>  |
| <b>ANSES</b>     | French Agency for Food, Environmental and Occupational Health and Safety / <i>Agence nationale de sécurité sanitaire de l'alimentation, de l'environnement et du travail</i>                                     |
| <b>AOC</b>       | Registered appellation of origin / <i>Appellation d'origine contrôlée</i>  |
| <b>CASDAR</b>    | <i>Compte d'affectation spéciale développement agricole et rural</i> (France)  |
| <b>CIHEAM</b>    | International Centre for Advanced Mediterranean Agronomic Studies – Montpellier  |
| <b>CIRAD</b>     | Agricultural Research for Development / <i>Centre de coopération internationale en recherche agronomique pour le développement</i> (France)  |
| <b>CNRS</b>      | National Center for Scientific Research / <i>Centre national de la recherche scientifique</i> (France)   |
| <b>CSR</b>       | Corporate social responsibility  |
| <b>DNCE</b>      | Diversity, Adaptation and Breeding of Grapevine research team of UMR AGAP  |
| <b>DAAV</b>      | National Oenology Diploma / <i>Diplôme National d'Œnologie</i>   |
| <b>EPHE</b>      | <i>École pratique des hautes études</i> (France)   |
| <b>ERDF</b>      | European Regional Development Fund   |
| <b>FADN</b>      | Farm Accountancy Data Network  |
| <b>FNEGE</b>     | French Foundation for Management Education / <i>Fondation Nationale pour l'Enseignement de la Gestion des Entreprises</i>  |
| <b>FP7</b>       | 7th Framework Programme of the European Union  |
| <b>FUI</b>       | Single Interministerial Fund / <i>Fonds unique interministériel</i> (France)   |
| <b>GI</b>        | Geographical indication  |
| <b>IAMM</b>      | Mediterranean Agronomic Institute / <i>Centre International de Hautes Etudes Agronomiques Méditerranéennes – Institut Agronomique Méditerranéen de Montpellier</i> (France)                                      |
| <b>ICT</b>       | Information and communication technology   |
| <b>IFV</b>       | French Institute for Vine and Wine / <i>Institut Français de la Vigne et du Vin</i>  |
| <b>IHEV</b>      | Institute for Higher Education in Vine and Wine Sciences / <i>Institut des hautes études de la vigne et du vin</i> (France)  |
| <b>INSERM</b>    | French Institute of Health and Medical Research / <i>Institut national de la santé et de la recherche médicale</i>   |
| <b>INRA</b>      | National Institute for Agricultural Research / <i>Institut National de la Recherche Agronomique</i> (France)   |
| <b>INTA</b>      | Institute of Agricultural Technology / <i>Instituto Nacional de Tecnología Agropecuaria</i> (Argentina)  |
| <b>IRD</b>       | French Research Institute for Development / <i>Institut de recherche pour le développement</i>   |
| <b>IRSTEA</b>    | National Research Institute of Science and Technology for Environment and Agriculture / <i>Institut national de recherche en sciences et technologies pour l'environnement et l'agriculture</i> (France)         |
| <b>LRI</b>       | Languedoc Roussillon Incubation (France)   |
| <b>ME</b>        | Medium-sized enterprise / <i>Entreprise de taille intermédiaire</i>  |
| <b>MSc</b>       | Master of Science  |
| <b>OIV</b>       | International Organisation of Vine and Wine  |
| <b>OMERE</b>     | <i>Observatoire Méditerranéen de l'Environnement Rural et de l'Eau</i> (France)  |
| <b>ONEMA</b>     | French National Agency for Water and Aquatic Environments / <i>Office national de l'eau et des milieux aquatiques</i>  |
| <b>OSU-OREME</b> | Observatory for Science of the Universe – Observatory for Research on the Mediterranean Environment / <i>Observatoire des Sciences de l'Univers – Observatoire de recherche méditerranéen de l'environnement</i> |
| <b>PET</b>       | Polyethylene terephthalate   |
| <b>PFP</b>       | Polyphenol platform / <i>Plateforme Polyphénols</i>  |
| <b>PGI</b>       | Protected geographical indication  |
| <b>R&amp;D</b>   | Research and development   |
| <b>SME</b>       | Small and medium-sized enterprises   |
| <b>UE</b>        | Experimental unit / <i>Unité expérimentale</i>   |
| <b>UM</b>        | <i>Université de Montpellier</i> (France)  |
| <b>UMR</b>       | Joint research unit / <i>Unité mixte de recherche</i>  |
| <b>UMT</b>       | Joint technology unit / <i>Unité mixte technologique</i>   |
| <b>VSE</b>       | Very small enterprise  |
| <b>UR</b>        | Research unit / <i>Unité de recherche</i>  |
| <b>WGI</b>       | Without geographical indication  |

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**Original Document Design:** Agropolis Productions

**Translation:** David Manley

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**Illustrations:**

we thank all contributors to this Dossier, as well as Guillaume Besqueut, Yvan Bouisson, Michel Calleja, Chantal Dorthe, Marie-Agnès Ducasse, Olivier Huttel, Andrew Kerr, Christophe Maître, Souhir Marsit, Sébastien Payen, Sabine Ragusi, Christian Slagmulder, Nicolas Sommerer, Frédéric Vèran, Clotilde Verriès, Nathalie Villeméjeanne.

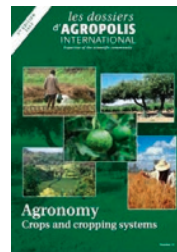
**Special Mention:** Philippe Psaila, photographer.

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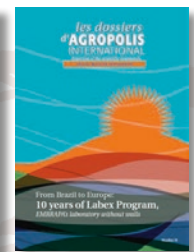
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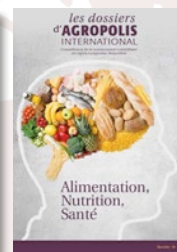
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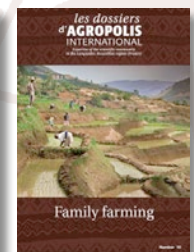
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