Vineyard management, agricultural practices and impact reduction

In 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)
The scientific aims of the Laboratory on Interactions between Soil, Agro systems 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
- 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.
**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 Observation 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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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.
Mappping vineyard evapotranspiration on a regional scale

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-1D 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.

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

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

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 (CO2, temperature). © psaila.net

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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.
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 7th 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).
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 Kampsomoromus 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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A Languedoc vineyard estate for vitiviniculture training and development

Domaine du Chapitre is one of the two experimental wine-growing estates of Montpellier SupAgro. This estate, which is located at Villeneuvelles-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 vitiviniculture 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 vitiviniculture estate scale and associate companies that implement the latest technological advances in agriculture (plot monitoring and 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 vitiviniculture sector, hosted by the Domaine du Chapitre business centre) and SMAG (Smart Agriculture, which develops and publishes agricultural software in Montpellier).