The aim of the MODEM_IVM project was to develop an interactive, web-based decision support system (DSS) for integrated management of the vineyard. DSSs are computerised information systems that support decision-making activities.

The project involved 8 partners (3 small and medium-sized enterprises (SMEs) and 5 research and technological development (RTD) institutes) settled in 4 European Union (EU) countries (France, Italy, Portugal, and Spain). The partners integrated their expertise for developing the complete DSS in terms of methodology, software and device. A prototype version of the DSS was delivered at the end of the project.

The DSS was developed by adopting an approach which aimed at overcoming all those limitations (both technical and of low acceptance by end-users) met up to now by DSS for crop management. The MODEM_IVM DSS is targeted to the vineyard manager, i.e. the person who makes decisions about the vineyard management or suggests the proper actions to the grape-grower (e.g. technicians of growers consortia, cooperatives or large farm enterprises, or private advisors), and it includes the following functionalities: decision supports for canopy management and for disease and pest control, estimate of plant protection products eco-toxicological impact, alert systems on potential abiotic stresses (low temperature injuries and water stress), and estimate of pending yield. The decision supports and alert provided by the system are formulated on the basis of simulation models outputs, and based on the best options for managing the vineyard according to the integrated production (IP). Besides the informatics infrastructure of the DSS, the MODEM_IVM project also developed and tested in three different EU sites a wireless sensor network (WSN) for a real-time monitoring of the vineyard environment; the weather data collected by this network feed the simulation models working within the DSS. In order to give a feedback to the models and to further tailor the outputs at field level, further information on the vineyard components can be collected with a scouting activity performed by means of hand held devices, a camera and a tablet, for monitoring grapevine plants, pests, and diseases. Specific applications for each device were developed and tested during the project. Models running within the DSS are stand-alone systems and can work without receiving input-data gathered with the scouting activity; nevertheless, the input from the scouting can strengthen the reliability of the outputs of the DSS at field level.

The MODEM_IVM DSS is characterised by the following features:

(1) holistic vision: functionalities on all the key aspects of vineyard management;
(2) specificity: DSS outputs are tailored to a single vineyard or a group of vineyards managed in a uniform manner;
(3) interactivity: each vineyard is characterised by site-specific information provided either by the user (e.g. soil texture) or by the wireless sensors (e.g. meteorological data);
(4) real-time update: the outputs of the DSS models are updated hourly;
(v) accessibility: the DSS is accessible via the Internet 24 hours a day / 7 days a week; vi) users interface: the surfing within the DSS is intuitive and dynamic; and
(7) systems update: the DSS functionalities are updated as soon as new results from research are made available.

The MODEM_IVM DSS will be released in a very important and highly profitable market that is grapevine production in EU27; the SME participants are strongly confident that the project results will improve their competitiveness. Benefits are also expected for the final users because the DSS will not only help them solving practical problems but it will also allow them to:

(a) implement the IP and integrated pest management (IPM) principles, in terms of a better resources management (i.e. soil, canopy and water) and a rational distribution of plant protection products;
(b) justify their actions when subjected to the compliance monitoring of the Directive on the Sustainable Use of Pesticides (2009/128/EC);
(c) reduce the environmental impacts of protection against diseases and insect pests;
(d) meet industry, community and government expectations about environmental management;
(e) improve the final product quality;
(f) maintain or gain access to certain markets, especially those with high standards for either quality of the product and/or environmental safety.

Project context and objectives:

The aim of the MODEM_IVM project was to develop an interactive, web-based DSS for integrated management of the vineyard.

DSSs are a specific class of computerised information system that support decision-making activities; their application to crop management has gained increasing importance since the 1980s. Nevertheless, despite their promises, DSSs have contributed little to practical IP (IP) because of the so-called ‘problem of implementation’ (lack of sustained use in a way that influences practice).

The DSS for integrated vineyard management, developed during the MODEM_IVM project, was purposely designed to overcome such a problem of implementation. The DSS was in fact developed by adopting the approach described by Magarey...
et al. (2002, Plant Disease 86: 4-14), who depicted a twenty-first century DSS as a ‘super consultant’ tool that:
(1) incorporates overall management solutions for growers;
(2) should not be designed or used to replace the decision maker but to help her / him in making choices by providing additional information;
(3) must be delivered through the web, for an easy and continuous updating;
(4) should have greater automation of interpretation than the current DSS.

Moreover, the DSS design focused also on aspects leading to a positive acceptance by the end users.

Specifically, the MODEM_IVM DSS is targeted to the vineyard manager, i.e. the person who makes decisions about the vineyard management or suggests the proper actions to the grape-grower (e.g. technicians of grower’s consortia, cooperatives or large farm enterprises, or private advisors).

8 partners were involved in the project (name, EU State, SME/RTD, Short name):

(1) Horta Srl, Italy, SME, HOR
(2) SODIMEL, SME, France, SOD
(3) GALTEL Proyectos y Desarrollos SL, Spain, SME, GAL
(4) Università Cattolica del Sacro Cuore, Italy, RTD, UCSC
(5) Universidad de La Rioja, Spain, RTD, UDLR
(6) Consiglio Nazionale delle Ricerche, Italy, RTD, IMATI
(7) Universidade de Tras-os-Montes e Alto Douro, Portugal, RTD, UTAD
(8) Centro Ricerche Produzioni Animali Spa, Italy, RTD, CRPA

The partners have different expertise with no or little overlapping of competences, well established on-going collaborations and common projects. HOR, a spin-off company of UCSC, aims at increasing the value of research by transferring into practice the technological innovation, mainly DSSs for integrated crop production and based on new information and communication technologies (ICT). SOD is specialised in developing instruments for automatic qualitative selection and management of grape bunches during harvesting or at the vinery, including tools based on image analysis for early estimation of the yield level of a vineyard. GAL works in three areas:
(i) wireless consultancy focused on cellular operators; % (ii) custom electronic designs, including hardware and software design; and
(iii) application of wireless technologies to agriculture.

Two institutes of UCSC are involved in the project: the Institute of Viticulture and Fruit tree production specialised in viticulture and the Institute of Entomology and Plant pathology specialised in plant pathogens epidemiology and disease forecasting. UDLR and UTAD carry out research in viticulture. IMATI is devoted to research in statistics and probability theory. The ICT department of CRPA brings its expertise in developing and deploying web applications.

Thanks to the integration of the different expertise described above, the project developed the complete DSS in terms of methodology, software and devices.

Specifically the MODEM_IVM DSS integrates the following components:

(1) a wireless sensors network (WSN) for real-time monitoring of the vineyard environmental conditions;
(2) hand-held devices for monitoring grapevine plants, pests, and diseases;
(3) a web-based tool which hosts the technological infrastructure of the DSS and
(i) analyses the data collected by the WSN and the hand-held devices using advanced modelling techniques;
(ii) optimises decision making;
(iii) suggests in the form of decision support the best options for managing the vineyard according to the IP; 
(iv) alerts on abiotic stresses;
(v) provides an estimate of pending yield.

In order to develop and integrate the above mentioned components, and therefore reach the project final goal, several objectives needed to be pursued in one or more project work packages (WPs):

(a) Development and integration in a single system of automatic sensors and hand-held devices for monitoring all the vineyard components (WP1).
(b) Development of models for the key processes involved in vineyard management: plant growth and development, abiotic stresses (cold injuries and water stress), diseases and insect pests (WP2).
(c) Analysis of the decision processes and development of decision supports consistent with the IP principles and based on the status of the vineyard and the environmental impacts of plant protection products (WP3).
(d) Development of an interactive, user-friendly, web-based portal that receives real-time data from the vineyard, uses these data as inputs for calculating optimised decision supports, and shows the decision supports in a clear way (WP4).

The new technologies and knowledge rising during the project as a result of the above mentioned activities were transferred from the RTD performers to the SMEs.

The final product, which was delivered by the project at the end of December 2012, is a DSS prototype and integrates the WSN, the hand-held devices, and the web-tool according to the scheme and the interactions described below.

The DSS provider closely interacts with the grapevine manager of the client enterprise for designing the best monitoring system for each particular situation. Afterwards, the DSS provider implements the WSN for monitoring the vineyard environment, provides the grapevine manager with the necessary hand-held devices for scouting the vineyard(s) during the season, and trains her / him in using both devices and the web-based DSS. The grapevine manager uses the DSS for inserting site-specific data for each crop unit (CU) (i.e. a vineyard or a group of vineyard grown on a uniform piece of land, with the same variety and trellis system, and cropped in an uniform manner all season long). During the season, the WSN monitors the
Decision-support systems (DSSs) are a specific class of computerised information system that support decision-making activities. A properly designed DSS is an interactive software-based system that helps decision makers obtaining useful information from raw data, documents, personal knowledge, and/or models in order to identify and solve problems and make decisions. DSSs can be as simple as a tool for processing data or as complex as a computerised expert system. A brief history of DSSs can be found in Power (2007). A review concerning the type, category, and fields of application of DSSs in agriculture was published about 10 years ago (Manos et al., 2004).

The MODEM_IVM DSS includes the following functionalities:

(a) decision supports for canopy management: severity and timing of summer pruning such as leaf removal and cluster thinning;
(b) decision support for disease control: downy mildew, powdery mildew, black rot, and Flavescence dorée;
(c) decision support for insect pests control: grape berry moth, Mediterranean vine mealybug, American grapevine leafhopper;
(d) plant protection products eco-toxicological impact;
(e) alert on abiotic stresses: low temperature injuries and water stress;
(f) estimate of pending yield.

Moreover, the MODEM_IVM DSS is characterised by the following features:

- Aim: designed as a ‘tool’ which provides additional and relevant information on the focus of the decision and not as a ‘proxy’ for the user’s decision process.
- Holistic vision: functionalities on all the key aspects of vineyard management (disease and insect pest management, canopy management, cold temperature and water stress, and pending yield estimate).
- Specificity: outputs tailored to a CU, i.e. a vineyard/s managed in a uniform manner all season long.
- Interactivity: CU characterised by site-specific information both static (e.g. soil texture) and dynamic (e.g. meteorological data).
- Real-time update of the outputs.
- Accessibility through the web 24 hours / 7 days.
- User-friendly interface.
- System update as soon as new results from research are made available.
- Co-innovation: the DSS was developed in collaboration with external consultants and a panel of final users.

The MODEM_IVM DSS will be released in a very important and highly profitable market, that is grapevine production in EU27; the SME participants are strongly confident that the project results will improve their competitiveness.

Benefits are also expected for the final users because the DSS will not only help them solving practical problems but it will also allow them to:

(a) implement the IP principles, in terms of better resources management (i.e. soil, canopy and water) and rational distribution of plant protection products;
(b) reduce the environmental impacts of protection against diseases and insect pests;
(c) meet industry, community and government expectations about environmental management;
(d) improve the final product quality;
(e) maintain or gain access to certain markets, especially those with high standards for either quality of the product and/or environmental safety.

Moreover, the functionalities dedicated to disease and insect pests management provide decision supports with a specific focus on the rationalisation of the use of chemicals, in terms of number of treatments (need-based and not calendar-based) and quality of the products (considering their potential eco-toxicological impact). Thus the DSS allows the grape manager to act according to the IPM principles. A specific benefit for the users is therefore the provision of criteria for justifying actions when subjected to the compliance monitoring on the observance of the Directive on the Sustainable Use of Pesticides (2009/128/EC), according to which IPM will be mandatory in EU by 2014.

Several activities of dissemination were successfully performed during the project:

(i) publication of the project web site (www.modem-ivm.eu);
(ii) information leaflets describing the project ad its final product;
(iii) a half-day international congress targeted to the potential DSS end users, held during an important international event of the grapevine-production chain;
(iv) publication of the knowledge developed during the project in scientific and technical journals;
(v) participation at congresses where the knowledge developed during the project was presented by means of oral presentations, posters and a dedicated stand;
(vi) seminars with and presentation of demonstration activities to potential end-users.

Project results:

State-of-the-art on DSS for crop management

Decision-support systems (DSSs) are a specific class of computerised information system that support decision-making activities. A properly designed DSS is an interactive software-based system that helps decision makers obtaining useful information from raw data, documents, personal knowledge, and/or models in order to identify and solve problems and make decisions. DSSs can be as simple as a tool for processing data or as complex as a computerised expert system. A brief history of DSSs can be found in Power (2007). A review concerning the type, category, and fields of application of DSSs in agriculture was published about 10 years ago (Manos et al., 2004).

DSSs collect, organise, and integrate all types of information required for producing a crop; DSSs then analyse and interpret the information and finally use the analysis to recommend the most appropriate action or action choices (Agrios, 2005). Expert...
knowledge, mathematical models, and timely data are key elements of DSS and are used to assist producers with both daily operational and long-range strategic decisions (Sonka et al., 1997). Computer-based DSSs have the potential to be important tools in the decision-making process for farmers and their advisers (Ritchie, 1995). DSSs can potentially include all the requirements for practical implementation of IP.

The importance of computer-based DSSs has steadily increased since the 1980s, and a large number of DSSs have been developed to assist extension agents, consultants, and growers in crop management. DSSs for example can provide users with information on plant disease risk by putting scientific knowledge and rational risk management algorithms at farmers disposal (Gent et al., 2011; Hochman and Carberry, 2011). Such information can be used for scheduling the treatments in a way to target them to the actual need of control. A review on the DSS currently available for crop protection in Europe was performed by the EC-funded ENDURE - Network of excellence in 2008 (ENDURE, 2010). Similarly, a list of DSSs for managing climate dependent farm business has been produced for Australia by a panel of experts, such a list is available on the web-site of the service Climate Keelpie (2012).

DSSs have generally contributed little to practical agriculture and, compared to the number of DSSs that have been developed, only a few are actually used on a routine base (Gent et al., 2011; Matthews et al. 2008; Nguyen et al., 2006). Although farmers want an enhanced ability to solve, resolve or avoid problems and uncertainty in decision making, DSSs are amongst the least preferred ways for achieving this goal (Stone and Hochman, 2004). The adoption of DSSs has in fact shown to be quite weak, with a number of users ranging between a few enthusiasts and up to just 3 % of the number of professional farmers in a single country (DCA, 2012). For example, the direct use of DSSs for crop protection by farmers is low, and the main use is indirect via agricultural advisors (ENDURE, 2008). Similarly, Jones et al. (2010) described as ‘super users’ those off-ce employees who access the systems for several weather stations and then distribute model outputs to people implementing the IPM on tree fruits.

As it was already pointed out at the beginning of the 2000s (McCown, 2002), DSSs for crop management faced, and are still facing (Matthews et al., 2008; McCown, 2012), the so-called information system ‘problem of implementation’, that is the ‘lack of sustained use in a way that influence practice’ (McCown, 2002).

Thorough analyses of the reasons of non-adoption and failure of DSSs in agriculture have been carried out by several authors, who in turn reflected on the possibility of recovering from the mistakes of the past (Hochman and Carberry, 2011; Ascough et al., 2010; Magarey et al., 2002; Matthews et al., 2008; McCown R.L. 2002; McCown et al., 2009; Parker et al., 1997; Stone and Hochman, 2004). Different factors have been identified to influence the adoption and sustained use of DSSs by agricultural users: profitableness, user-friendly design, time requirement for DSS usage, credibility, adaptation of the DSS to the farm situation, information update, and knowledge of the user (Kerr, 2004). Under-utilisation can be ascribed to both technical limitations and farmers’ attitude towards decision making and perception of DSSs (Gent et al., 2011; Matthews et al., 2008).

LIMITATIONS OF THE EXISTING DSSs

Many of the technological problems met during the 1990s, and recognised to be an obstacle to the adoption and sustained use of DSSs, have been significantly reduced by the increased availability of personal computers, access to the Internet, and development of web-based programs (Jones et al., 2011). Nevertheless, despite the development and diffusion of ICT occurred over the last decades and the fact that the current generation of producers are adopting computers at the same rate of the general public (Ascough et al., 2010), some limitations still exist. Technical limitations can be summarised as follows:

- The key aspects of the production are not considered altogether: Most DSSs addresses only specific problems, whereas crop managers must deal with a wide range of issues generated over the entire production process.
- Poor-quality: Some models are pushed into service before being sufficiently refined and validated.
- Not enough user friendly interface.
- Time consuming: the use of several DSSs takes too long because of delays in data processing or tedious input requirements.
- Information delivered at time intervals not compatible with decision making and action; 6. lack of regular maintenance and updating.

The low rate of success of DSSs in agriculture, despite the progressive overcoming of several limitations met during the 1990s, has brought the attention to the importance the potential users give to the role these systems play in the decision-making process (McCown et al., 2009; Matthews et al., 2008). It was considered that the DSS providers had ‘an excessive focus on technological factors rather than recognising the need to ensure that the tools developed are credible with decision makers and to integrate the software into a particular decision making milieu’ (Matthews et al., 2008).

Resistance towards DSSs often derives from their designed role in decision making: DSSs typified as proxy for a user decision process (e.g. elaborate expert systems) have been unsuccessful because farmers felt their decision process by-passed (McCown, 2002). Rather than making decisions on behalf of the users by prescribing an action as the optimal solution, DSSs should attempt to help crop managers satisfying their needs in a working reality which is characterised by high uncertainty and complexity (Hochman and Carberry, 2011; McCown, 2002). In this way DSSs assume the role of a tool which provides information relevant on the focus of the decision and that the users can consider and apply according to their own decision-making process (Stone and Hochman, 2004; McCown, 2002); DSSs then complement the decision-making process without excluding the users from it (Stone and Hochman, 2004). For this reason, DSSs serving as tools have generally experienced higher use compared to those designed as proxy.

Another factor which influences the adoption rate of a DSS is the establishment of its practical impact and market credentials (Stone and Hochman, 2004). In the context of crop management, the introduction of a DSS represents a ‘sustaining innovation’ which requires a significant change in practice (or behaviour) (McCown et al., 2009). Compared to the cultivation of a new crop variety, which is defined as a continuous technology, the adoption of a DSS is defined as a discontinuous technology; this adoption requires the implementation of new work procedures at the farm level, such as for instance routine field inspections or the consultation of ICT tools (DCA, 2012). In order to embark on a challenging adoption of a DSS, potential users need therefore to recognise the relevance that this kind of systems can have on their activity as well as the resulting benefits (McCown et al., 2009).
Involvement of the potential users during the DSS development has been identified as a way of avoiding the implementation problem (McCown, 2012; Oliver et al., 2012; Igbaria and Guimarães, 1994). User’s involvement has proved to significantly impact on: perceived DSS benefits, overall user satisfaction, and DSS usage (Igbaria and Guimarães, 1994).

The innovative approach of the MODEM_IVM project

The aim of the MODEM_IVM project was to develop an interactive, web-based DSS for integrated management of the vineyard. Specifically, the DSS is targeted to the vineyard manager, i.e. the person who makes decisions about the vineyard management or suggests the proper actions to the grape-grower (e.g. technicians of grower’s consortia, cooperatives or large farm enterprises, or private advisors).

This DSS was purposely designed in a way to overcome the so-called ‘problem of implementation’, described in the previous paragraphs. In particular, the approach for developing the MODEM_IVM DSS was the one described by Magarey et al. (2002), who depicted a 21st century DSS as a ‘super consultant’ tool that:

(i) incorporates overall management solutions for growers;
(ii) should not be designed or used to replace the decision maker but to help her / him in making choices by providing additional information;
(iii) must be delivered through the web, for an easy and continuous updating;
(iv) should have greater automation of interpretation than the current DSSs. Besides addressing these characteristics, the MODEMIVM approach also focused on aspects that could lead to a positive acceptance from the end-users. During the MODEM IVM project, in fact, potential users were involved and their participation was crucial because they provided an insights on their decision processes and on the criteria adopted to decide actions. Establishment of the DSS impact and of its market credentials were also considered to show potential benefits to future users. Seminars and visits to demonstration vineyards were organised; in these vineyards, performances achieved in plots managed according to the vine managers usual practice were compared to those achieved by considering the supports provided by the DSS. According to the adopted approach the MODEM_IVM DSS is a tool that helps the user making choices by providing additional information, so that the user remains responsible for the choice and the implementation of actions.

MODEM_IVM DSS

The MODEM_IVM project developed the complete DSS in terms of methodology, software and devices. Specifically, the DSS integrates the following components (see also the attached image):

1. a WSN for real-time monitoring of the vineyard environmental conditions;
2. hand-held devices for monitoring grapevine plants, pests, and diseases;
3. a web-based tool which hosts the technological infrastructure of the DSS and:
   (i) analyses the data collected by the WSN and the hand-held devices using advanced modelling techniques;
   (ii) optimises decision making;
   (iii) suggests in the form of decision support the best options for managing the vineyard according to the IP;
   (iv) alerts on abiotic stresses;
   (v) provides an estimate of pending yield.

In this DSS, the provider closely interacts with the decision makers for designing the best monitoring system for each particular situation. Afterwards, the DSS provider implements the WSN for monitoring the vineyard environment (weather and plants), provides the grapevine manager with the necessary hand-held devices for scouting the vineyard(s) during the season, and trains her/him in using both devices and the web-based DSS. The grapevine manager uses the DSS for inserting site-specific data for each vineyard. During the season, the WSN monitors the vineyard environment and sends data to the DSS in real time via the GPRS. The DSS analyses data and produces the decision supports; when necessary, the DSS asks the grapevine manager to scout the vineyard through the hand-held devices, and to send information. The decision supports help the grapevine manager make decisions about management options. The system includes a continuous updating of the DSS and its adaptation to the client needs. This process involves a feedback from grapevine managers and the involvement of researchers who have been involved during the project as well as other researchers with specific expertise.

The key features of the MODEM_IVM DSS are the following ones:

1. Aim: the DSS has been designed as a ‘tool’ which provides additional and relevant information on the focus of the decision and not as a proxy for the user decision process.
3. Specificity: the decision supports and alerts provided by the DSS are tailored to a CU, that is a vineyard (or a part of a vineyard or number of vineyards) managed in a uniform manner all season long.
4. Interactivity: each CU is characterised by means of site-specific information both static, which do not change over the season and are provided una tantum by the user to the DSS, and dynamic, which change over the season.
5. Real-time output update: the DSS receives in real-time the data collected in the vineyard and uses them as input variables of the simulation models running within the system, so that the outputs of these models are updated hourly.
6. Accessibility: the DSS is a service delivered via the Internet and accessible by any browsers, always available 24 hours a day. 7 days a week, and it does not require the installation of specific programmes.
7. User interface: the surfing within the DSS portal is intuitive and dynamic and allows to choose the level of detail at which exploring the information provided by the system. Such information is displayed in a graphic form that makes use of colours and symbols able to communicate in an immediate, effective, and univocal way the state of each component of the vineyard management.
8. System update: the accessibility via the Internet allows a timely update of the DSS functionalities, as soon as new results from research are made available and without requiring the user interventions.
9. Co-innovation: the DSS was developed in close collaboration with external consultants and a panel of final users in order to appropriately address their needs. During the project, potential users were involved in seminars and visits to demonstration vineyards and their participation was crucial because they provided an insight on their decision processes and on the criteria adopted to decide actions.
The web portal is accessible for the project partners via the project website [see http://www.modem-ivm.eu online for further details] and for the final users via the web site of Horta, the SME coordinator of the project [see http://www.horta-srl.com online for further details]. The access is performed by means of an authentication process, which requires to enter a username and password.

The web portal hosts the actual DSS and offers a series of functionalities, which can be consulted by the user when he / she needs to take a decision for managing the vineyard. Each functionality is dedicated to a specific component of vineyard management. In particular the DSS collects, organises, and integrates in an automatic way the information constantly coming from the environmental monitoring performed by the WSN and the site static information of the CU provided by the user. The DSS analyses these data by means of advanced modelling techniques and produces supports and alerts on the basis of model outputs. The mathematical models working within the DSS have been either developed by the researchers involved in the MODEM_IVM project or retrieved from literature and adapted and calibrated for properly fitting the general DSS architecture.

After the log-in to the DSS, the user selects one of the CUs he/she is managing and gets access to the alerts and supports tailored on such CU. The system first displays a main page from where it is possible to access the DSS functionalities. These functionalities provide information in real-time and can be explored at different level of detail. In general, two levels of details are available: a synthetic one, which shows the latest information available at the moment of consultation and can communicate the degree of alert (for most functionalities the synthetic overview is shown in the main page, for others it is accessible by clicking on a dedicated button on the same page); and an in-depth one, which shows in a graphic form the dynamic development of the functionality outputs over the season. The graphic layout of the outputs is simple and intuitive and makes a functional use of the colours.

For example, the synthetic information on disease is provided in the form of small dashboards, one for each considered disease, showing an index of alert, the level of which is represented by colours varying from green (low alert), to yellow, to orange up to red (very high alert). The in-depth information, accessible by clicking on the disease dashboard, shows graphs of the temporal evolution, at daily interval, of the different phases of those processes which lead to the infection and the outbreak of symptoms.

The functionalities embedded in the DSS are the following:

- Weather data: last hourly data recorded by the sensors installed in the vineyard and series of daily values of rain, leaf wetness, air temperature and relative humidity.
- Decision support for canopy management: severity and timing of summer pruning operations such as shoot thinning, leaf removal, clusters thinning.
- Alert on abiotic stresses: (a) low temperature injuries; (b) water stress.
- Decision support for disease control:
  (a) downy mildew;
  (b) powdery mildew;
  (c) black rot.
  (d) flavescence dorée.
- Decision support for insects control:
  (a) Lobesia botrana;
  (b) Planococcus ficus;
  (c) Scaphoideus titanus.

Indicators of plant protection products eco-toxicological impact

MODEM_IVM DSS COMPONENTS - THE WSN

Weather sensors are integrated in a weather station or specifically located in the vineyard to collect the following environmental variables: air temperature, relative humidity, rain, leaf wetness, solar radiation, soil temperature, soil water content, barometric pressure, wind direction and wind speed. The WSN was assembled and tested by Galtel, the Spanish SME involved in the project, over the two growing seasons of MODEM_IVM in the three experimental vineyards managed by the RTD partners specialised in viticulture: one vineyard in Italy managed by USCS, one in Spain managed by UDLR and another one in Portugal managed by UTAD.

The sensors allow to monitor the vineyard environment in real-time and to collect the information used to produce the inputs feeding the models working within the DSS.

MODEM_IVM DSS components - The hand-held devices: The scouting application

A scouting application, for both tablet and PC, was developed during the project for guiding the user in monitoring activities on the actual status of the plant and the presence of diseases and insect pests. In particular the scouting functionalities are the following:

- Plant: Assessment of the growth stage (according to the BBCH scale).
- Plant: Number of unfolded leaves.
- Plant: Assessment of the canopy density (in terms of bunch visibility).
- Plant: Assessment of the vegetative-reproductive balance (in terms of leaf area-bunch ratio).
- Plant: Assessment of the water stress, to be performed only if the DSS provides a water stress warning (in terms of active vegetative apexes and average leaf inclination).
- Plant: Stress characteristics (in terms of spatial and temporal distribution of symptoms).
- Diseases: Downy mildew - Presence of lesions.
- Diseases: Powdery mildew - Presence of ascosporic lesions.
- Diseases: Powdery mildew - Presence of spherical fruiting bodies.
The DSS and all the mathematical models running within it are designed to work as stand-alone systems, which do not require the provision of other data besides the environmental data recorded by the sensors in the vineyard and the initial site-static information provided by the user; nevertheless, data coming from scouting activities performed at field level can increase the systems performance.

MODEM_IVM DSS components - The hand-held devices: The camera
A camera for monitoring the cluster weight evolution was developed by Sodimel, the French SME involved in the project, and tested over the two growing seasons of MODEM_IVM in two experimental vineyards: one vineyard in Italy managed by USCS and the other one in Spain managed by UDLR.

The use of this device allows to forecast grape yield on the basis of pictures of clusters taken in the vineyard and successively handled with a specific image treatment software.

Contribution to advancement of knowledge and of technological progress
The MODEM_IVM project has enhanced significantly the state-of-the-art in the area of DSSs for vineyard management for the following reasons.

A holistic vision of grape cultivation problems: The MODEM_IVM DSS embraces the concept of the integrated approach in designing multidisciplinary DSSs. This DSS takes into account and provides decision supports for all the key elements of the production chain, from strategic choices to tactical operations. In this way, the DSS overcomes one of the main obstacles to widespread practical use of other DSSs, which is an inadequate consideration of all aspects of production.

Converting complex decision processes into simple decision supports: The MODEM_IVM DSS for vineyard management uses sophisticated technologies and methods for analysing data to produce simple and easy-to-understand decision supports. In this way, the DSS combines the advantages of both simple DSSs (low cost, ease of delivery in multiple ways, and limited time requirements for learning and use of the DSS) and more sophisticated ones (greater integration of knowledge, greater grower choice of management tools and consideration of associated risks). The DSS is therefore an easy-to-use tool that performs a complex task efficiently and effectively.

Transferring scientific knowledge into practice: The MODEM_IVM DSS is delivered via the World Wide Web; this:
(i) increases accessibility;
(ii) allows the DSS to be updated easily and continuously, so that new knowledge can be provided to users in a fast and efficient manner; and
(iii) allows users to maintain hands-on contact with the provider.

The DSS uses both push and pull systems: push systems deliver information to the user, while pull systems require the user to request the information. The push system will be used for supplying daily information, updates, and other types of dynamic information, while the pull systems will work for allowing users to access specific on-request information.

Coupling information at territorial and crop scales: In Europe, regional or district scale information products are provided by extension services and, especially, by public services (Rossi et al., 2000). For instance, the Plant Protection Organisation (PPO) of the Emilia-Romagna Region, in Italy, provides public advice, usually on a weekly basis, on the current and forthcoming risks for some pests and diseases, and suggestions about the use of pesticides according to the regional IPM guidelines. Growers can freely access this information, usually through the Internet or articles in local newspapers. The MODEM_IVM DSS for vineyard management does not conflict with this information but enlarges its efficacy by bringing information from the territorial scale to the plot scale.

Providing criteria for justifying actions: The trend in agriculture is toward more complex, technologically based crop management, with greater regulation and supervision by both government and processors on the use of chemicals (fertilisers, pesticides, etc.). The Thematic Strategy on the Sustainable Use of Pesticides adopted in 2006 by the European Commission aims to establish minimum rules for the use of pesticides in the Community so as to reduce risks to human health and the environment from the use of pesticides. The Directive 2009/128/EC requires a mandatory use of IPM in all the EC Member States by 2014, and asks governments to establish and apply methods for determining whether farmers apply IPM principles in practical crop management. In this context, site-specific data, scouting reports, and recommendations from the MODEM_IVM DSS will serve as acceptable criteria for justifying (to regulatory authorities, but also to wholesalers, processors and consumers) the application of chemicals.

Involvement of end-users: during the MODEM_IVM project, potential users were involved and their participation provided insights into their decision processes and criteria adopted to decide actions. Moreover, the involvement of end-users can help establishing the DSS impact and market credentials.

Literature cited
- Power D.J. 2007. A Brief History of DSSs. DSSResources.COM Available at (last verified March 2013): http://dssresources.com/history/dshistory.html
- Stone, P. and Z. Hochman, 2004. If interactive DSSs are the answer, have we been asking the right questions? In: New directions for a diverse planet. Proceedings of the 4th International Crop Science Congress, 26 Sep. 1 Oct 2004, Brisbane, Australia.

Potential Impact:

IMPACTS FOR THE END-USERS

The MODEM_IVM DSS for grapevine management is targeted to the vineyard manager, i.e. the person who makes decisions about the vineyard’s management or suggests the proper actions to the grape-grower. Therefore, end-users can be:
(i) advisors of grower’s consortia, cooperatives or large farm enterprises;
(ii) private advisors / consultants, or
(iii) grape-growers. The adoption of the DSS and, consequently, the practices of sustainable agriculture, will promote a better business for each of these categories.

Grape-growers will take advantages in:
(i) better use of the natural resources (soil, canopy, and water) for future grape production;
(ii) reduction of certain inputs (e.g. pesticides, water, etc.);
(iii) reduction of the costs for protecting the vineyard against pests and diseases by means of a significant reduction of the number of treatments;
(iv) increase of the quality and quantity of the production, thanks to a better management of both biotic and abiotic stresses;
(v) reduction of the labour demand for managing the vineyard;
(vi) reduction of the costs for technical advice;
(vii) demonstrating to customers and to the general community good environmental performance;
(viii) meeting industry, community and government expectations about environmental management;
(ix) maintaining or gaining access to certain markets, especially those with high standards for either quality of the product or environmental safety.

Quantifying all these economic advantages is not an easy task and have been demonstrated in only a few cases. Limiting this evaluation to costs for plant protection, Caffi et al. (2010, 2012) conservatively estimated that the use of DSSs to manage powdery and downy mildews in viticulture reduce PPP applications by 30%; given that conventional application of PPPs for control of these diseases costs about 500 EUR / ha per year, a DSS can reduce the cost by 150 EUR / ha per year.

Advisors and consultants will take advantage of the possibility to better assist their clients and members of growers association by reducing the necessary time to acquire information and to elaborate possible suggestions. They will also be able to optimise the visits to grape-growers planning only the ones really needed on the basis of the DSS advices. It can be estimated that technical assistance to a farm enterprise occupies on average 15 working days per year, including desk work and field visits. It can be also estimated that the adoption of the MODEM_IVM DSS will reduce this time by about 50%; therefore, a two fold increase in working capacity can be expected. This will return to growers in the form of reduced costs for technical assistance.
Furthermore and as already mentioned, the adoption of the MODEM_IVM DSS will provide criteria for justifying actions and will allow growers to easily respect laws and regulations, including the Directive 2009/128/EC on the Sustainable Use of Pesticides. In this context, the possibility for the European professional users of organising the vineyard pest management on the basis of the guidance of the DSS will provide them with evidence of a rational use of pesticides.

IMPACTS for the European Community

The impact of the MODEM_IVM DSS for the EU community must also be considered as an added value of this project. In fact, this DSS can have a positive impact on the European viticulture and wine industry. The DSS can represent for the grapevine managers of all Europe an efficient and easy-to-handle tool, able to support their decisions on the basis of scientific data.

The management of the European vineyards on the basis of the IP guidance offered by the MODEM_IVM DSS can have several beneficial effects for grape-growers, which are listed in the previous paragraph. The DSS can therefore make the grape-growers more competitive producers in a leading market for the viticulture such as the European one. For instance, the total cost of fungicides used to protect European vineyards is EUR 1.91 billion per year in EU-27; the reduction in the use of pesticides consequent to the use of DSS is estimated as EUR 573 million per year.

Besides the positive economic impact, the reduction of the use of pesticides can have significant ecological advantages for the European community. In the DSS-based vineyard management, the use and quantity of chemicals are optimised and limited to the strictly necessary, allowing a higher respect of the environment but maintaining the same productivity levels. To date, 69 819 tons of pesticides are employed each year to protect grapevine in Europe (Eurostat, 2007). Considering 30% as an average saving of treatments rising from the use of the DSS, the reduction in pesticide quantity distributed is 20 646 tons per year for the whole Europe. This represents an indirect, but not secondary, impact for:

(i) the quality of life, health, and working conditions of grape-growers (about 2.4 million people over EU-27);
(ii) food safety and health of the consumers;
(iii) the environment.

For these reasons, this project is in full agreement with the EC document ‘Assessing economic impacts of the specific measures to be part of the Thematic Strategy on the Sustainable Use of Pesticides’ ENV.C.4/ETU/2003/004R.

Dissemination activities

Scientific and technical knowledge concerning results was disseminated during the project by means of:

(a) a website which includes an overview of the project partners, information contacts, summaries and a photogallery of the work performed, and list of events (participations at conferences, demonstration and dissemination events). The website of the project is available at http://www.modem-ivm.eu;
(b) an information leaflet for advisors, consultants, and grape-growers;
(c) a half-day international congress targeted to the end-users, on 29 November 2012 during Vinitech Sifel in France, an important international event of the grapevine-production chain;
(d) publication of the knowledge developed during the project data in peer-reviewed scientific and technical journals;
(e) participation at congresses where the knowledge developed during the project was presented by means of oral presentations or posters, or in a dedicated stand.

The project was also presented to the students of the Maymester of the Purdue University (USA), who visited the UCSC vineyard on May 2012 during their stay in Italy.

All the documents published within the project, as well as the web site, acknowledged EC citing the following sentence: ‘The research leading to these results has received funding from the EU’s Seventh Framework Programme (FP7) managed by Research Executive Agency (REA) (FP7/2007-2013 (FP7/2007-2011)) under Grant Agreement No 262059’.

Demonstration activities are also considered part of the result dissemination. Two demonstration events were organised in Italy and Spain, respectively on 27 June in Piacenza and on 13 December in Logrono. Three seminars were organised in Italy, Spain, and France, respectively on 22 June in Piacenza, on 3 July in Viladecans and on 29 November in correspondence of the international conference at Vinitech Sifel in Bordeaux.

Exploitation of the project results

The SME participants (HOR, SOD, GAL) retain the full ownership of project results. The ownership of these project results (i.e. the foreground) is distributed among the SMEs in relation to their area of business and in proportion to their investment in the project. The project results will be commercially exploited by the SME participants as a whole or as single components depending on the client requirements. The single components to be exploited are:

(1) wireless sensors for monitoring the vineyard (owned by GAL);
(2) application for tablet / PC for performing scouting activity in the vineyard (owned by GAL);
(3) camera for plant monitoring (own by SOD);
(4) web-portal hosting the DSS for integrated vineyard management (owned by HOR).

It is planned to put the project results onto the market on the second year after the project end (2014). In the first year after the project end, the web portal will be freely provided to ten leader farms in key grape-growing areas across Europe. In this year, each SME will cover its own costs.

Exploitation of the whole system will be fulfilled through 'regional privileges'. The regional privileges do not apply to exploitation of the single components of the system, i.e. any SME can singularly offer the components of its ownership in any country.

Literature cited

List of websites: http://www.modem-ivm.eu info@modem-ivm.eu

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