FEASR

REGIONE DEL VENETO

PSR VENETO 2014-2020

FONDO EUROPEO AGRICOLO PER LO SVILUPPO RURALE: L'EUROPA INVESTE NELLE ZONE RURALI

Innovative sensors in the vineyard for Downy mildew infections forecasting

pvsensing.it

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Measure 16 "Cooperation" - RDP Veneto Region

Innovation is one of the transversal priorities of rural development and is one of the main tools for the competitiveness and sustainability of farms. In order to encourage the innovation process in agriculture, the Rural Development Program (RDP) recognizes a fundamental role in the "Cooperation" Measure (Measure 16), which is aimed at overcoming economic, environmental and other disadvantages deriving from the fragmentation of innovation processes.

The Operational Groups, which are funded through Measure 16, are partnerships in which at least one of the component subjects has the status of an enterprise in the agricultural or agri-food sector, or their association, and which may include other subjects functional to the performance of a series of activities, whose ultimate goal is the development of innovation. The Operational Group, starting from the detection of the need for innovation, is formed around a theme of practical interest for companies.

For more information we recommend to visit the websites:
www.psrveneto.it
https://ec.europa.eu/eip/agriculture/en

SUMMARY

The problem: GRAPEVINE DOWNY MILDEW

A problem for the crop yield

Plasmopara viticola is the pathogen causing the downy mildew of the grapevine, a "fungal" disease among the most important in viticulture which is widespread all over the world. Such a pathogen can infect all the green organs of the vine, including shoots, leaves and clusters until the green stage. The infection symptoms come as "oil spots" on the leaves which, in favourable conditions of temperature and humidity, develop a delicate, white, cotton-like mildew on the underside of the leaf (sporangiophores emerging from the stomata). From such a sporulation new infections spread, by dissemination of the sporangia to other green tissue, through wind and rain splash. Young clusters are also affected giving rise to sporulation, while the berries in advanced stage become brown without the external emission of sporangiophores. The presence of the first symptoms in the field can give rise to an epidemic situation, destructive for the crop yield. The defense of grapevine from downy mildew is thus necessary and fundamental for the success of the grape harvest and it is one of the main challenges for winegrowers.

Fig. 1. Symptoms of grapevine downy mildew, in order from the left: oil spots on leaf, sporulation the underside of leaf, sporulation on cluster, infection without sporulation on advanced cluster.

An economic and environmental problem

Downy mildew has represented, since the end of the 19th century, a real economic problem for the entire world viticulture, with evident differences between the wine-growing areas, depending on the climatic conditions, more or less favorable to the pathogen, according to the vintage. In Italy it is certainly the most important cryptogamic disease, especially in the Veneto region, where the climate is particularly suitable for its development. Such a disease is proven to have the greatest weight in the phytosanitary management of the vineyard, having a considerable impact on both environmental and economic sides, as it can be seen from the graph in figure 2 and from the data in table 1.

Total cost of defence	**1,720 - 2,180 €/ha**
Global defence cost ratio on the total operating costs	34-36 %
Downy mildew cost ratio on the total defence costs	20-22 %

Tab.1. Cost ratio due to downy mildew defence interventions (data taken on a sample of 60 companies in Veneto, average of 2015-2016-2017).

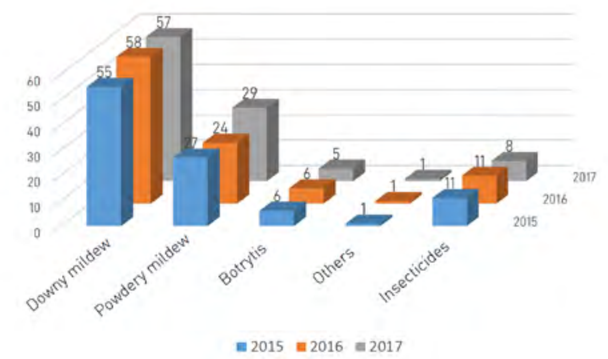

Fig. 2. Average annual percentage/hectare of fungicide and insecticide spraying divided by adversity (data taken on a sample of 60 companies in Veneto). Source: CIRVE

According to ISPRA data ("Italian national report on pesticides in water, data 2013-2014") in Veneto region the 47.8% of the monitored areas have pesticides residues in surface or underground waters: many of them are anti-cryptogamic substances used in viticulture against downy mildew. Even for organic agriculture, with the use of mainly copper-based products, there is the problem of copper accumulation in the soil, so that the allowed doses of such products are being regulated by increasingly restrictive bounds.

An innovative forecasting model

The life cycle of *P. viticola* strongly depends on the climatic conditions. The temperature and the presence of water, in particular, regulate the main steps of the development of the infection.

Monitoring the climatic variables through field sensors allows to reconstruct the life cycle of the pathogen with a certain accuracy. A forecasting model, i.e. a set of algorithms, implemented in software code, processes the climatic data collected by the sensors, together with the weather forecast, providing as an output an index of infection risk. The common forecasting models usually consider as input variables: rain, temperature and humidity of the air, leaf wetness, wind speed.

The PV-sensing project aims to develop and evaluate on field an innovative forecasting model for downy mildew infections, in which some new variables are measured in the field and considered as an input, with the aim of making more accurate the simulation of the life cycle of the pathogen and thus the forecast of infections. Novel electronic sensors are tested in the project to detect new quantities, not only of a climatic nature, but also related to vegetative development.

A forecast model is an important tool for the winegrower as a support to decisions about the vineyard management. The user can indeed know, from objective data, when there are favorable conditions for an infection and the actual necessity to perform a phytosanitary treatment. Such a system should allow a rationalization of the pesticides use, avoiding the waste of resources in unnecessary treatments, that are sometimes performed on the basis of an uncertain knowledge on the infection risk.

Decreasing the pesticide use can lead to a positive saving of resources, with consequent economic and environmental benefits.

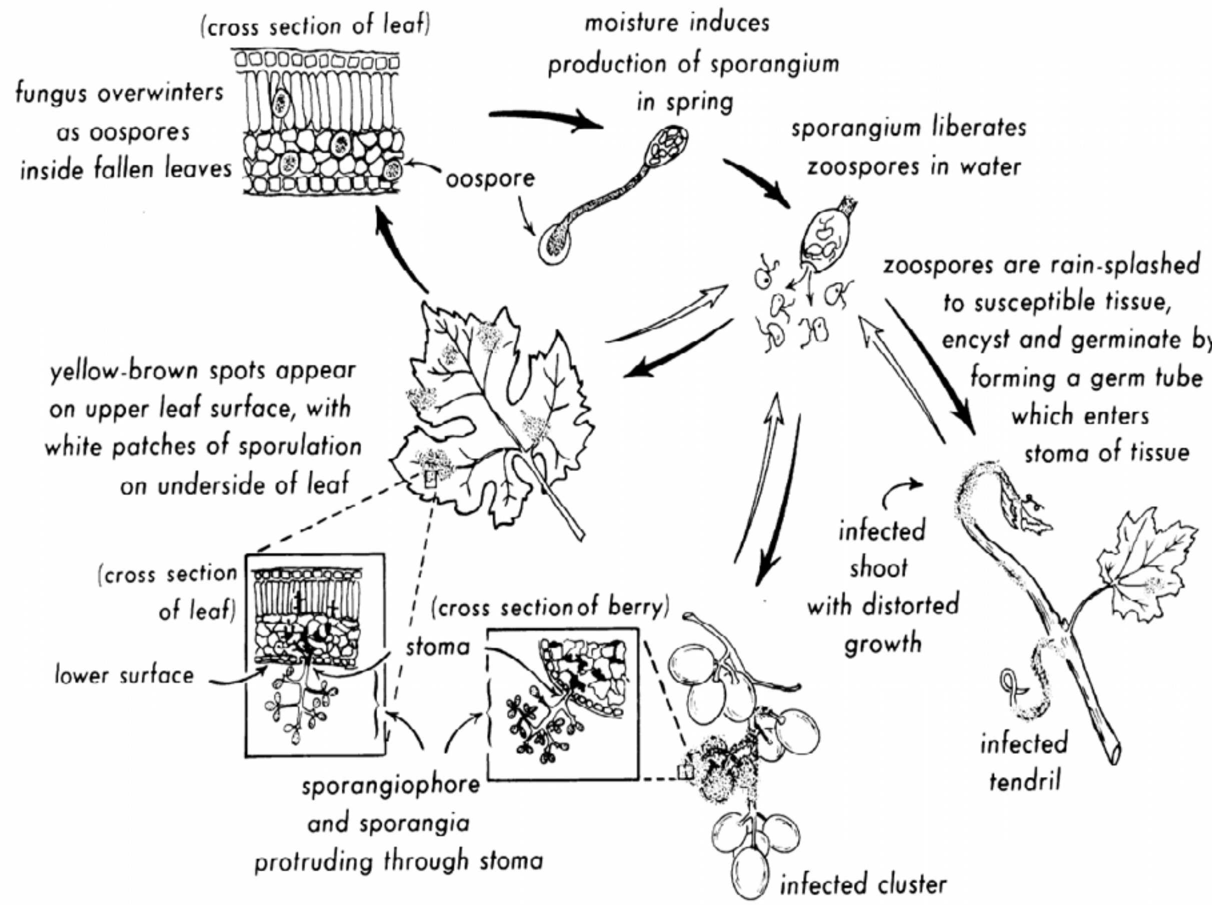

Fig. 3. Plasmopara viticola life cycle. Source: New York State Agricultural Experiment Station, Grape IPM Disease Identification Sheet N. 5.

The PV Sensing sensor set

The PVsensing project is based on a set of innovative sensors that for the first time are tested on the field. Project activities mainly aim to collect data for a better understanding and simulation of the life cycle of *P.viticola*, used to elaborate a more precise and reliable infection risk index, to be implemented in the forecast model.

Canopy volume and leaf area

Fig. 4. Weather station integrated with the "WCAM" device, a special camera for monitoring and measuring the vegetation growth.

A precise measurement of canopy volume and leaf surface is carried out by the "WCAM" device, a particular camera suitable for permanent installation in the field, which uses sophisticated automatic image analysis techniques for the recognition of the foliage and its three-dimensional reconstruction. *P. viticola* is an obliged parasite of the vine vegetation tissues, which is more or less susceptible to the infection depending on the quantity of open stomata leaf surface being present and unprotected. The measurement of this aspect is thus of fundamental importance for a greater precision in the prediction of infections, adapting the forecast model to the specific vegetation conditions of the vineyard, which depends on several local variables and on the specific vine management.
The measures provided by the system are also useful for optimizing the dosages of plant protection products, adapting them to the vegetation growth.

Temperature and moisture at the surface soil level

Fig. 5. One of the experimental sensors used on the ground for measuring humidity in the soil surface layer.

The superficial soil moisture and temperature are fundamental variables for assessing a model of maturation and germination of the *P. viticola* oospores, wintering on the soil surface. From the oospores germination the primary infections start, following the spring rains. The correlation of primary infections with the direct soil surface moisture is investigated for the first time in this project: it should be a determining factor for quantifying the "pressure" of primary infections to which the vineyard is subjected during the season.

Measurements are obtained by a set of experimental sensors for soil moisture and temperature, which differ from the common soil moisture probes, as the measuring mechanism, patented, involves only the first millimeters of the soil, i.e. those where the oospores actually overwinter and can germinate.

Leaf wetness and dew drip

Fig. 6. The leaf wetness and water dripping sensor tested in the project.

To determine the risk of infection by *P. viticola*, it is very important to know the temperature, air humidity and leaf wetness status by sensors placed inside the canopy. The "dripping" is an innovative measurement taken by the "LWS-PLUS" sensor, capable of detecting when the overnight accumulation of dew on leaves is such to cause the water drip from one leaf to another. In presence of infection, the dripping water holds the pathogen spores and drags them from leaf to leaf and on clusters, causing passible new infections. Dripping also affects the wash off of plant protection products, even in the absence of rain. Monitoring this phenomenon allows a more precise and reliable definition of the infection risk.

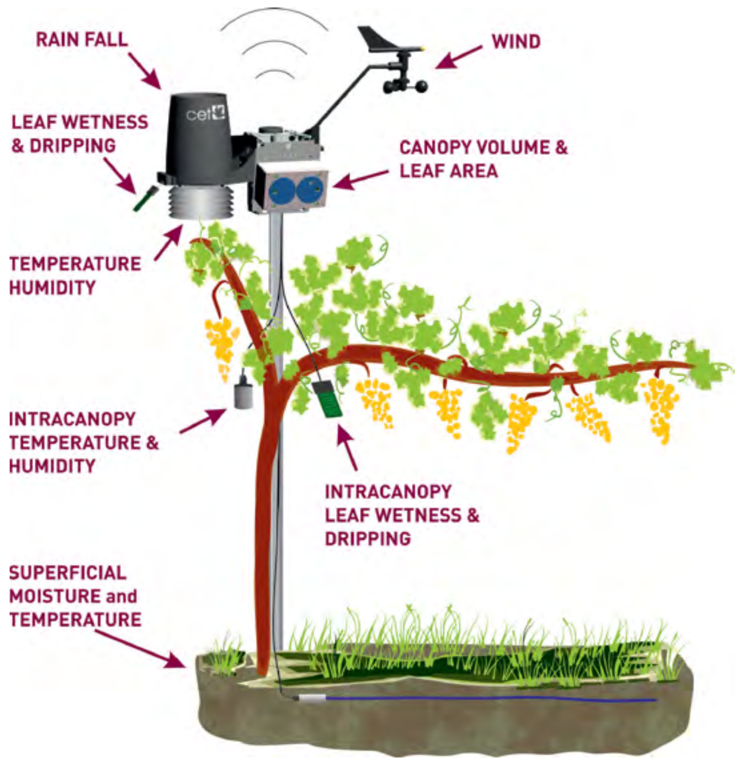

Fig. 7. The variables measured in vineyard by the set of new sensors, according to the experimental setup in each trial plot.

In total 11 farms in the Veneto region, some with conventional and some with organic management, participated in the field trial by hosting the set of sensors in the the vineyard, during the vintages 2018 and 2019 (now ongoing in 2020). Data collected from the trials have been used to calibrate the forecasting model based on the innovative inputs of the sensors.

Fig. 8. WEB monitoring of the risk indices and of all the data detected by sensors in the field.

The field trials

The new variables introduced in the PVsensing project are for the first time measured automatically by sensors located in the field. The potential of the innovative measures can be investigated and exploited only through a field data collection focused on the infection outbreaks, in order to find the right relationships between the variables and the infection symptoms, calibrating the forecast model.

The main activity of the PVsensing project consists precisely in the very rich data collection on downy mildew infections, carried out in 11 vineyards of the project partners, in the vintages 2018 and 2019: 5 with Glera variety in the conventional regime, 5 with Glera variety in the organic regime and 1 with Merlot variety in an organic regime. The trial sites are located in different areas of the province of Treviso, in the Veneto region, characterized by different soil and climatic conditions (Figure 9).

The full set of sensors has been installed at each trial site, for the measurement of climatic and vegetative variables. Portions of vineyard rows where to constantly carry out the surveys on downy mildew symptoms during the season, were delimited in each site, identifying:

- Untreated tests (UT): plots of two interpals of a row (from 8 to 12 vine plants), covered with special tarpaulins during the phytosanitary treatments, in order to avoid contamination with the products due to the drift effect; multiple tests were opened during the season, from 3 to 6 per farm, each of which has lost treatments in a given time range;

- Treated tests (TT): plots of 10 interpals (from 40 to 60 vine plants per farm) corresponding to the vineyard normally treated with fungicides.

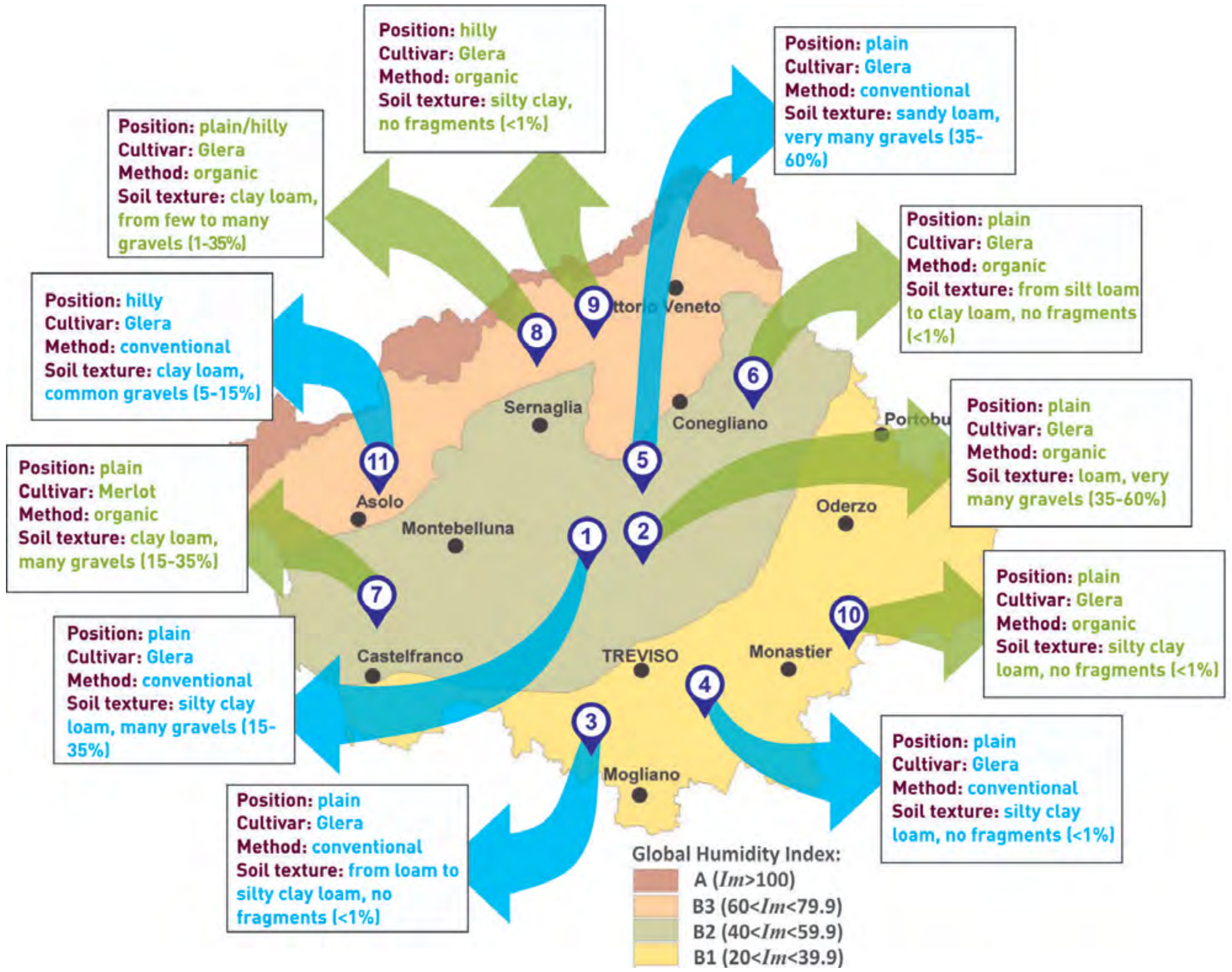

Fig. 9. Location of the 11 PVsensing experimental sites and their characteristics. In the background, a soil map with respect to the global humidity index Im according to Thornthwaite (1948). $Im = \left(\frac{P - ETP}{ETP}\right)\cdot 100$, *with P the annual precipitation (mm) ETP the annual average evapotranspiration potential (mm). Source: Province of Treviso and ARPAV (Veneto Regional Agency for Prevention and Protection of the Environment).*

Field surveys about downy mildew symptoms were performed both on leaves and on clusters, at least twice a week, checking all the vegetation present in the reference tests. Unlike other survey techniques, which usually involve random sampling of leaves and bunches, we kept observing all the reference vegetation in the test plots, so that it was possible to detect more precisely the temporal evolution of the infections from the first stage. An absolute number of infections was detected, related to the vigor of the canopy, then normalized as "infections per meter of row". This made it possible to compare the various experimental plots taking into account the specific vigor of the vines at each site, measured in terms of volume and leaf area by the "WCAM" device.

The detected infections were noted down following a specific experimental protocol defined within the project, including the annotation of the total number of new infections (observed at each survey in each test plot) and the detailed characterization observed on a sample of leaves and bunches as an evolution of: dimensions, state of sporulation and presence of necrosis.

The contemporary surveys on UT and TT plots allowed to collect very important data about the conditions of development of the infections and to compare the effectiveness of the different fungicide treatments set by each company. In particular, the adoption of multiple UT plots, opened at different stages of the season, allowed us to observe which treatments were really crucial for preventing downy mildew in the different field trials.

The surveys on infections were also accompanied by surveys about phenology and vegetative development.

Fig. 10. Tarpaulin system used for the protection of UT plants during the phytosanitary treatments.

Fig. 11. Group of technicians working during field surveys on untreated test parcels.

Fig. 12. Oil spot detection on a leaf and size measurement for detailed characterization

Fig. 13. Detection of sporulation symptom on a small grape cluster in formation.

Agronomic results

Climate trend

In 2018 the temperatures in February-March were rather low, with heavy rains in March, which continued with less intensity until mid-April. In 2019 there were abundant spring rains (April-May), accompanied by significant drops in temperature: this situation favored a strong pressure of primary infections in 2019, with earlier oubreaks of the first symptoms, observed in the field trials, althought the appearence was delayed by low temperatures.
In June, the rains decreased significantly in number and intensity, while the temperature values increased significantly.

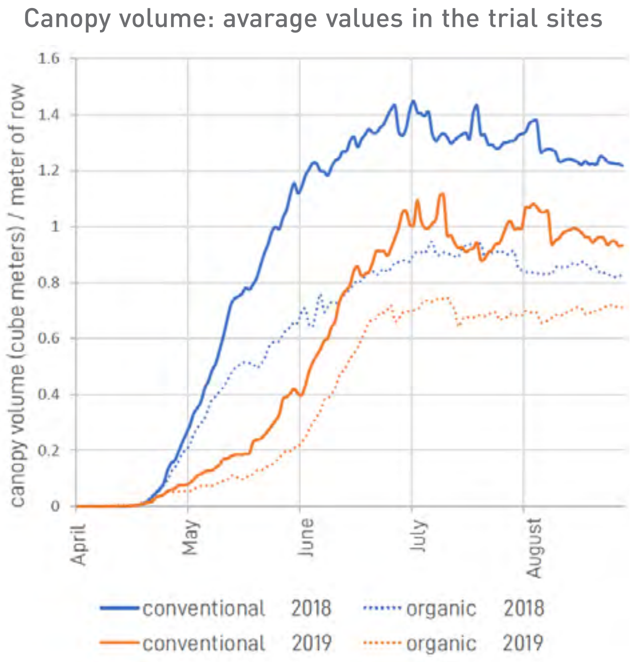

Fig. 15. Average trend of the canopy volume measured in the two years of tests in the experimental sites.

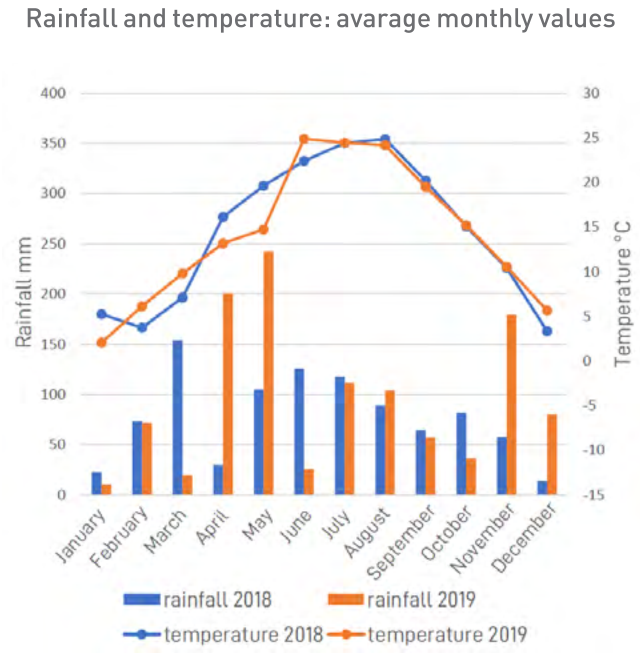

Fig. 14. Average monthly values of rainfall and temperatures in the two years of tests in the experimental sites.

Vegetative development

In 2018, the sprouting of the vine occurred late compared to the previous year; the development substantially returned to normal following the thermal rise in April-May. In 2019 after the initial start of budding, the thermo-pluviometric trend in the months of April-May resulted in a delay of the flowering phase, which is also confirmed in the subsequent phenological phases. The vigor of the foliage reflects the delay in 2019, undergoing a drastic slowdown in May, confirmed later in the season, with lower values of the canopy volume compared to the previous year.

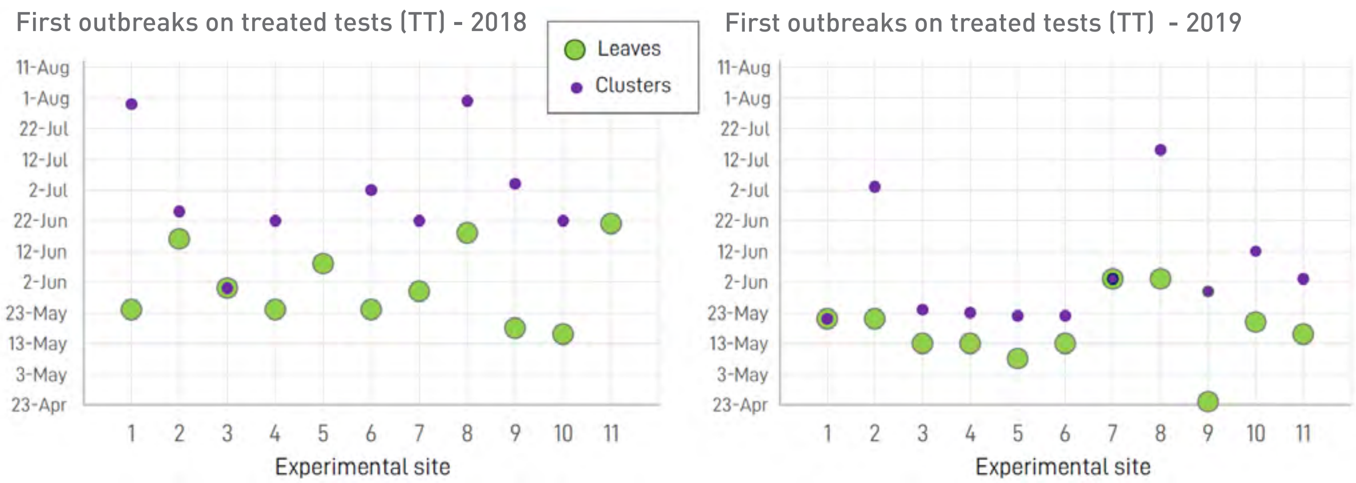

Fig. 16. Dates of detection of first symptoms on leaves and clusters in the TT at the 11 trial sites, in the two vintages.

Evolution of epidemics in treated parcels

In 2019 the meteorological trend of the spring period influenced the development of downy mildew in the vineyard: the first infections, due to continuous rains and wetting, were quite widespread even in in the treated parcels (TT), where they tended to be appear earlier than in the year 2018 (see fig. 16).

Simulations from the forecasting model

The data collected from the field surveys have been used at different stages for the adaptation of the model algorithms, in order to optimize the calibration of the forecast model. The results obtained so far are encouraging and leave space for further improvements, which will be gradually introduced in the next future. Figure 17 shows, by way of example, the performance of the output provided by the model with respect to the leaf infections observations in two different experimental cases on the untreated tests. The trends are consistent with the field surveys, especially in 2019, the year in which more data were collected for a more precise calibration.

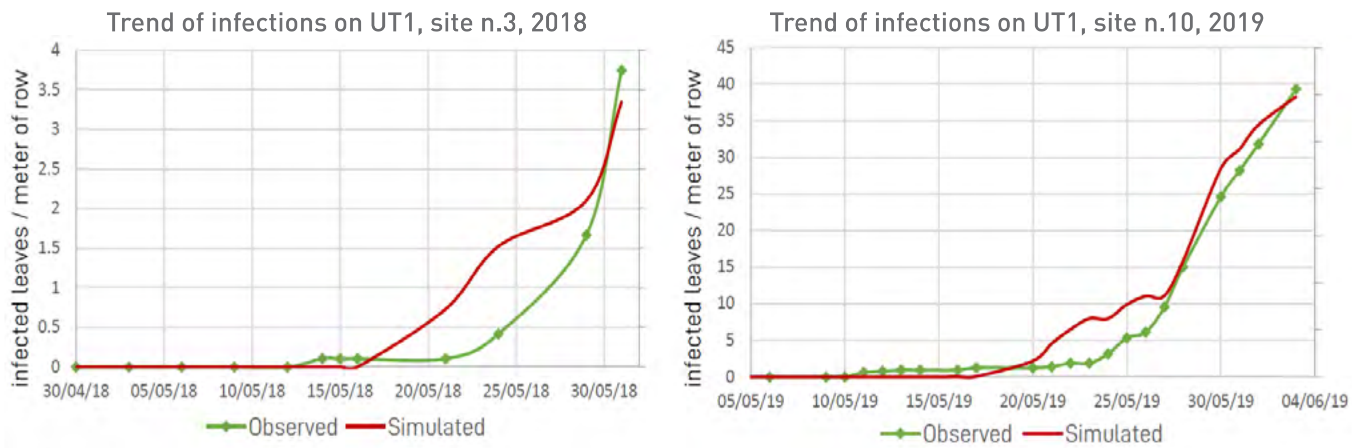

Fig. 17. Evolution of the infections simulated by the model and observed in the vineyard. The absolute values of the model were rescaled to allow comparison with the data collected in the field.

To get a first indication of the predictive capacity of the model, graphs have been drawn up on the basis of the "new infections risk" output values provided by the model. Figure 18, by way of example, shows the seasonal trend of infections predicted in the experimental cases already mentioned in figure 17. This allowed a first rough comparison with the forecasts produced by the PVsensing model with other reference models.

It's worth noting a greater frequency of spring infections reproduced in 2019, which characterized all the experimental sites and found full confirmation in the field infections observations. These values were used to simulate the virtual treatments suggested by the model *a posteriori* and to carry out the related economic-environmental analysis (see next section).

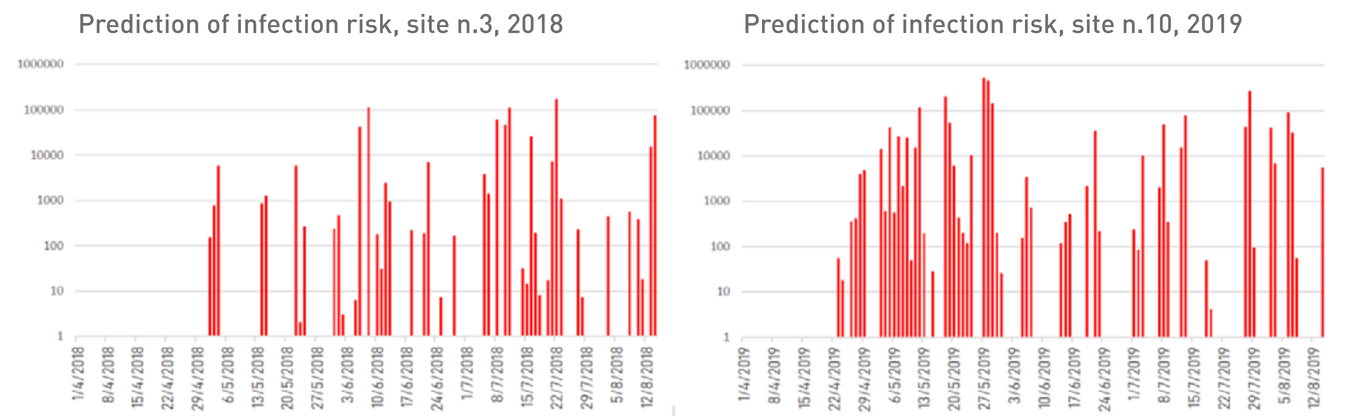

Fig. 18. Dates of infections and their intensity (on a logarithmic scale) simulated by the model.

Economic and environmental impact: preliminary assessments

Economic impact

The costs for disease control in the vineyard are subject to considerable variability, depending on the management strategies, the available technology and the environmental conditions. The phytosanitary interventions carried out by the partner farms in the 2018 and 2019 vintages were analyzed, differentiating by organic and conventional production method, in order to define some reference costs for evaluating the economic impact of the technological innovations in PVsensing.

The total defense costs of the vineyard are divided into: spraying costs, costs for downy mildew control, for powdery mildew, for insects and other costs, including the use of biostimulants and resistance inducers.

The first data collected from the partners in the two-year observation period indicate that the average number of interventions, as well as the cost estimate, is in line with those of the Veneto region wine sector, basing the analysis on the market prices of the plant protection products and the used doses.

The number of treatments against downy mildew appears strongly influenced by the rain distribution. From the first indications, based on the ex-post evaluations of the model forecasts, the use of the PVsensing system allows a tendential reduction in downy mildew treatments. Table 2 shows a summary of the data collected in the partner companies (average years 2018-2019):

	COMMON MANAGEMENT		PVsensing MANAGEMENT		
Method:	N. of treatments (downy mildew)	Defense cost euros/hectar	N. of treatments (downy mildew)	Defense cost euros/hectar	Cost variation
Organic	17.2	1.181	14.4	991	-16,1 %
Conventional	14.4	1.205	12.9	1.077	-10,6 %

Tab. 2. Comparison between the number of treatments and defense costs against downy mildew between the average company management and the one estimated with the PVsensing system.

As regards, for example, the 2019 vintage, the graph in fig. 19 shows how, in the conventional conduction method, the main cost item was that for the use of anti-downy mildew products, which account for 46% of the total average cost.
Organic farm management shows a lower defense cost in absolute terms with higher costs for spraying (due to the greater number of treatments done). Other products, namely resistance inducers and biostimulants, which are used in strict link to the control of downy mildew in organic conduction, account for 24% of the total cost, while anti-downy mildew products register an incidence of 10% on the total cost.

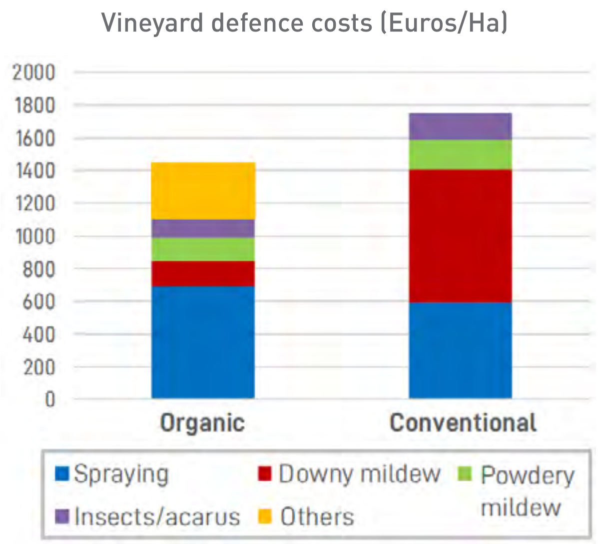

Fig. 19. Division of global vineyard defence costs.

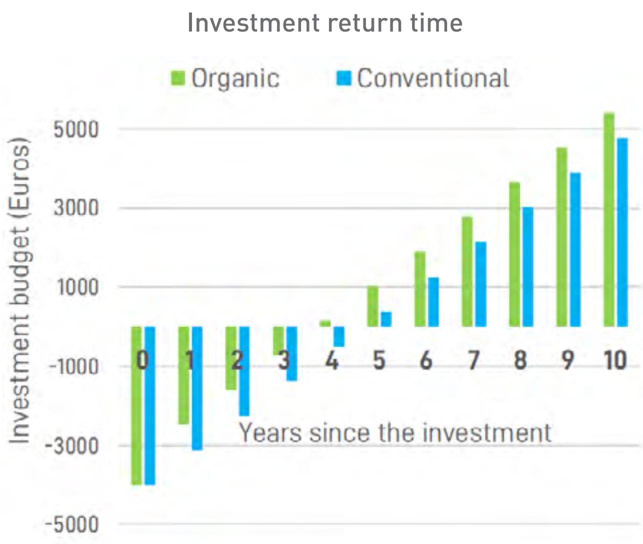

Fig. 20. Estimated return time of investment based on defense saving costs (on 10 Ha).

The PV sensing stations allow to monitor and manage homogeneous vineyard areas of approximately 10 hectares, with an estimated duration of at least 10 years. The graph in fig. 20 shows the estimates of the return time of the investment, equal to 4 years for organic and 5 years for conventional management, in vineyards with an extension of 10 Ha. This calculation was made on the basis of the average investment costs in sensors, the annual software management costs and the savings in defense costs. It should be noted that this estimate does not take into account the impact on the containment of downy mildew infections in the vineyard, due to a more correct positioning of the phytosanitary interventions, allowed by the use of sensors and the forecast model. While this is not exactly quantifiable by the current data, the system may improve significantly the quality and quantity of the vineyard yield, indeed. Such a result can be particularly important in years with high disease pressure, thus accelerating also the economic return.

Environmental impact

The impact on the environment and human health was assessed through the CIP (Potential Impact Class) indicator developed by the Regional Agency for Environmental Protection of the Tuscany region (ARPAT). The CIP index quantifies the degree of environmental and sanitary impact generated by the use on the territory of the active ingredients contained in plant protection products. These effects are evaluated on a scale whose value varies from 1, minimum effect, to 5, maximum effect.

For each partner farm and year of production, the CIP sector (environment, water and health) was calculated by averaging the sum of the CIP of each active ingredient, weighted for the relative dose used by the company. The analysis of anti-downy mildew treatments carried out in the two-year period generally highlights normal CIP indicators for the water and environment sectors and medium-low indicators for the health sector. The higher values for the organic conduction on the water and environment compartments are the consequence of a greater use of substances that create bioaccumulation in the considered matrices (copper). The potential effect of the adoption of the PVsensing model was estimated with a reduction in the average CIP values of the sector calculated proportionally to the variation of the suggested downy-mildew treatments. The results of the calculation, for the average of the two-year period 2018-2019 for the partner companies, are shown in table 3.

	WATER CIP		ENVIRONMENT CIP		HEALTH CIP	
Method:	Common	PVsensing model	Common	PVsensing model	Common	PVsensing model
Organic	2.79	2.34	3.34	2.80	0.99	0.83
Conventional	2.08	1.86	2.56	2.29	2.62	2.34

Tab. 3. Comparison between the avarage CIP values of the different sectors in the common farm management and with the use of the PVsensing model.

Conclusions and perspectives

What presented so far is the result of a preliminary study, based on only two vintages and resulting from their specific climatic trend. In particular, the high rainfall of spring 2019 surely weighed on the number of treatments needed against downy mildew, regardless of the use of the novel technology.
The experimental design of the project, dedicated to a first collection of the field data necessary for the calibration of the forecast model, led to the hypothesis on the reductions in the cost of defense and environmental impact on the basis of ex-post evaluations. A more exhaustive study should be produced with field validation tests in which the infection risk forecasts provided by the model are directly adopted as a defense strategy by the companies. This may highlight not only a reduction in treatments but, above all, how the correct positioning of the same can make the difference in the agronomic management. It's interesting, for example, noting how some cases of epidemic spread of downy mildew infections in 2019, on treated vineyards, were due to treatments carried out by the company too early with respect to the rains and to the very fast growth of vegetation, in the early stages of the season.
The progressive refinement of the forecast model, using the data already collected and the comparison with new seasons, will significantly improve the presented results.

The Operational Group

Partners:

CANTINA SOCIALE MONTELLIANA E DEI COLLI ASOLANI: leader partner of PVsensing project, this wine cooperative receives grapes produced by 395 conferring members. The grapes come from the hilly areas of Montello and Asolo and the area near the cities of Treviso and Castelfranco Veneto.

CANTINA DEL TERRAGLIO: cooperative formed by nearly 200 wine growers members who come from Treviso, Venice and Padua areas. The winery, due to its innovation vision, for twenty years by now has been organizing technical assistance about the vineyard management for its members.

SOCIETÀ AGRICOLA 7 NARDI S.A.S. DI NARDI CLAUDIO E C.: organic farm with 12,5 ha of vineyards, most of them planted with Glera cultivar (Prosecco Docg wine), and the rest with varieties like Cabernet, Verdiso, Chardonnay, Manzoni Bianco and Merlot. Organic farm for 30 years.

TERRE GROSSE SOC. AGR. S.S.: organic company since 2018 with 7 Ha of vineyards in with 16 grape's varieties, like Glera (Prosecco Doc wine) and some local cultivars, like Raboso and Grapariol.
Terre Grosse deals with the direct grape production, its transformation into wine and wine sales.

AZ. AGR. ZAMPERONI UGO: farm with 16.4 hectares of hillside vineyards, most of them planted with Glera (suitable for Prosecco d.o.c.g.) and Pinot Gris. The company operates in a conventional regime.

SOCIETÀ AGRICOLA F.LLI DA LOZZO DI DA LOZZO ANDREA E GIANNI S.S.: organic winery (10.7 hectares), with predominant varieties of Glera (Prosecco d.o.c.) and Pinot Gris, followed by Chardonnay, Merlot and Pinot Noir. The company takes care of the production of grapes, of its transformation into wine and of final saling.

AZ. AGR. BISCARO FRANCESCO: organic farm consisting of 3.64 Ha, 3.27 of which cultivated in vineyard. The main variety is Glera, followed by Merlot and Cabernet Sauvignon.

AZ. AGR. BOTTAZZO MIRTO: farm operating in conventional regime, with 75 Ha, of which 12.33 Ha are cultivated with vineyards. The main variety is the Glera (Prosecco d.o.c.), followed by Merlot, Pinot Gris, Cabernet Sauvignon, Chardonnay and Cabernet Franc.

SOCIETÀ AGRICOLA ABM S.S.: farm operating in conventional regime, member of Cantina del Terraglio, it has a vineyard area of 6.38 ha with Pinot Grigio (2.9 Ha) and Glera suitable for Prosecco d.o.c.

AGRIBEDIN DI BEDIN ELVIS: Company with 11.2 Ha of vineyards with the varieties: Pinot Gris, Pinot Noir and Glera (Prosecco d.o.c.) The company operates under a conventional regime.

The PVsensing Operational Group was promoted and managed by a large group of partners with different skills, who have experimented and disseminated the project activity thanks to the Veneto Rural Development Program.

UNIVERSITÀ DEGLI STUDI DI PADOVA – CENTRO CIRVE: the center is leader in Italy in viticulture's research and training thanks to a team of qualified researchers, innovative projects and training activities. The Center is composed by researchers from DAFNAE (Department of Agronomy, Animals, Food, Natural Resources and Environment) and by TESAF (Department of Land and Agro-Forestry Systems) of the University of Padua.

CET ELECTRONICS SNC: since 1976 the company (SME) deals with the design and the production of electronic and computer systems. Specialized in sensors, remote control and automation systems in various application sectors, in the last 10 years has been focusing on monitoring systems for agriculture, viticulture in particular. CET is the developer and the manufacturer of the technology tested in this project.

CONFAGRICOLTURA VENETO: Confagricoltura Veneto is the regional expression of the General Confederation of Italian Agriculture, the first agricultural Association by date of birth and tradition. Confagricoltura protects italian agricultural companies and pursues agricultural development in all its aspects (economic, social and technological).

I.S.I.S.S. DOMENICO SARTOR: this scholastic institute presents three different agricultural courses: "Agricultural, agri-food and agro-industry techinician", "Agricultural and rural development services" and "Agricultural operator". Inside the institute there's a farm annexed to the school, in which students can manage two vineyards, including phenological, phytosanitary and oenological evaluations and experiments.

CREA-VE: the Viticulture and Oenology Research Center is one of the national centers of the Council for Agricultural Research and Economics (CREA) (CREA). CREA-VE operates in the research and experiments of the viticulture sector, especially focused on conservation, characterization and enhancement of the grape's germplasm, diagnosis and defense against diseases and cultivation techniques.

pv·sensing

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Organization responsible for information: Gruppo Operativo PVsensing
Managing authority: : Regione del Veneto - Direzione AdG FEASR e Foreste

project leader

MONTELLIANA

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cet electronics www.cet-electronics.com

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TERRE GROSSE ZENSON 1931

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ISTITUTO AGRARIO DOMENICO SARTOR

PERLAGE WINERY 7NARDI

Az. Agr. F. Biscaro

CANTINA DEL TERRAGLIO FONDATA NEL 1964

F.lli Da Lozzo

Confagricoltura Veneto

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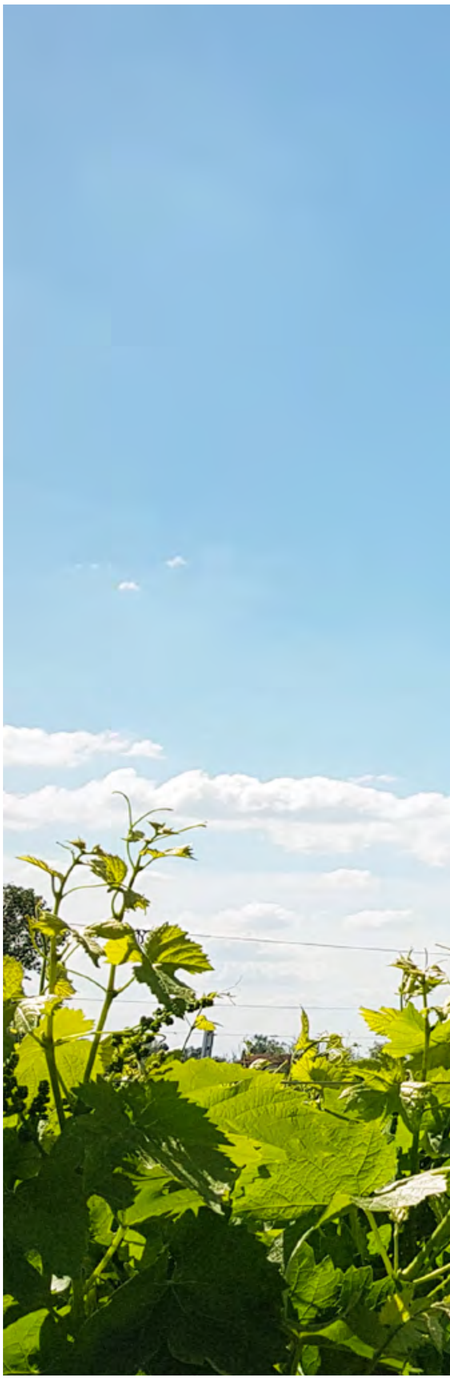
PROGETTONATURA



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