Wireless meteorological sensors in the Sulcis territory to run predictive models of vine diseases

WIRELESS METEOROLOGICAL SENSORS IN THE SULCIS TERRITORY TO RUN PREDICTIVE MODELS OF VINE DISEASES

SENSORI METEOROLOGICI WIRELESS NEL TERRITORIO DEL SULCIS PER ALIMENTARE MODELLI PER LA PREVISIONE DELLE MALATTIE DELLA VITE

Irene Salotti[1], Giovanni Paolo Colucci[2], Elena Filipescu[2], Paola Battilani[1]*, Daniele Trinchero[2]

[1] Department of Sustainable Crop Production, Università Cattolica del Sacro Cuore, 29122 Piacenza, Italy
[2] iXem Labs, Department of Electronics and Telecommunications (DET), Politecnico di Torino, 10129 Torino, Italy
* paola.battilani@unicatt.it

Abstract

In the last forty years, several plant disease models have been developed for the main fungal and oomycete diseases of grapevine. The current study aims to structure a platform for wireless collection of meteorological data to feed the joint use of predictive models. To this purpose, the territory of Sulcis, in South-West Sardinia, has been selected, where 14 agrometeorological stations have been operational since 2018 in locations exposed to various weather conditions, inhomogeneous altitudes and different soil textures. Based on literature search, models with different characteristics, available for four grape diseases (downy and powdery mildews, grey mould, and black rot) have been selected and translated in R to be connected to the meteorological data source. Models' evaluation has been performed highlighting differences and similarities in data input and output. In perspective, model output consistency will be evaluated with data collected by Cantina Santadi, a relevant grape producer in the territory to define model performances and suitability to support farmers and technicians in crop protection decision making.

Keywords

Plant disease modelling, crop protection, agrometeorological platforms, Internet of Things, LoRaWAN

Parole chiave

Modelli previsionali, difesa integrata, piattaforme agrometeorologiche, Internet of Things, LoRAWAN

Introduction

The sustainable management of grape diseases caused by oomycetes and fungi represents a major challenge of modern viticulture. The use of plant protection products, in fact, impacts on farms' economic and environmental sustainability.

On average, 12 to 15 fungicide applications are performed every year, mainly for the control of downy mildew and powdery mildew, caused by *Plasmopara viticola* and *Erysiphe necator*, respectively. Since their first occurrence in the XIX century, the control of these pathogens has strongly relied on chemical applications during the entire growing season to protect both leaves and bunches. Management of mildews is particularly difficult due to their polycyclic nature, especially when primary infections lack timely control. Furthermore, occasional or emerging diseases such as grey mould (caused by *Botrytis cinerea*) or black-rot (caused by *Phyllosticta ampelicida,* syn. *Guignardia bidwellii*) may develop into severe epidemics, leading to quantity and quality yield losses.

To uptake rational disease control and reduce negative impacts of chemicals on human health and the environment, mathematical models have been developed starting from the 1980s. Their adoption, however, is still limited due to social and economic barriers, as well as technological constraints for accessing reliable weather data and forecasts. Nevertheless, the use of models for monitoring plant diseases is a pillar of Integrated Pest Management (Directive EC/1128/2009) and recommended in organic agriculture, where the list of available products is further limited (Rawat et al. 2021). The use of plant disease models to address tactical decisions and reduce the application of chemicals has been reported in several research studies. For instance, Rossi et al. (2014) reported that the consultation of models integrated in a decision support system reduced the amount of copper applied for disease control by 37% in 21 grape-growing, organic farms in Italy.

Therefore, plant disease models have the potential to boost the transition of viticulture towards a sustainable, low-input regime. However, the awareness in the use of models should increase to guarantee a reliable support for tactical decision-making in crop protection. The aim of the current work is to develop a platform for wireless collection of meteorological data, to feed the joint use of predictive models with different characteristics, available for four grape diseases of concern. Models' evaluation has been performed highlighting differences and similarities in data input and output. To this purpose, a territory in South-West Sardinia has been selected, because of the presence of a well-structured and widely deployed proximal agrometeorological network, with 14 stations operating since 2018 in locations exposed to various pedoclimatic features and inhomogeneous altitudes and distance from the sea.

Materials and Methods

The case of study

The analysis has been applied to the Sulcis territory, in the South West of Sardinia (Fig. 1), in collaboration with Cantina di Santadi, a local cooperative farm that collects more than 90 farmers, covering an area of about 200 hectares (Table 1). This is an ideal location to analyze different plant disease models, as terrain texture and inclination vary over short distances. Moreover, weather exposition is very different, with some vineyards located by the sea, being exposed to strong mistral winds and high salinity, while some others are located in valleys, with persistent dew during a large part of the night. Grape varieties include local ones, like Vermentino, Carignano, Nasco, Cannonau, Monica and Nuragus, paired with international ones in limited quantities, mainly Chardonnay, Cabernet and Merlot.

Tab.1 - Vineyards location
Tab.1 - Localizzazione dei vigneti

Vineyard	Latitude	Longitude	Municipality
Is Marroccus	39.108136	8.712621	Santadi
Crabì	39.074941	8.727271	Santadi
Barrua Carignano	39.070076	8.697767	Santadi
Perdaxius	39.142353	8.622524	Perdaxius
Tratalias Triangolo	39.102805	8.588734	Tratalias
Fronte Stagno	38.983613	8.592139	Sant'Anna Arresi
Su Portu de Su Trigu	38.987353	8.577439	Sant'Anna Arresi
Is Cuccus	39.038523	8.610768	Masainas
Paniesu	39.023279	8.620082	Sant'Anna Arresi
Agto Villarios	39.059625	8.602707	Giba
Canigonis	39.031427	8.593404	Masainas
Villaperuccio	39.118124	8.676418	Villaperuccio
Is Muras	39.063481	8.639228	Giba
Bidacioni	39.1546394	8.6587635	Narcao

Weather data platform

The iXemWine platform has been exploited to retrieve the required agrometeorological data for testing the different selected models. The platform has been developed by the iXemLabs at Politecnico di Torino. Regarding the transmission technology, a Low Power-Wide Area Network (LP-WAN) system has been adopted, which uses LoRa radios in the Physical Layer and the LoRaWAN protocol in the MAC Sublayer. As Network Servers, the ones available on the open platform released by The Things Network (TTN) have been selected. The iXemWine application server has been used to gather, memorize, visualize and share the measured data.

Commercial sensors have been chosen and wired to the LoRaWAN end-node implemented on a custom Printed Circuit Board (PCB). This device hs been developed for collecting and transmitting data from the sensors, using a Murata module (type 1SJ) that integrates a microcontroller from the STM32L0 family (by STMicroelectronics) and the SX1262 radio chip (by Semtech) into a single component, powered by 2 AA alkaline batteries in series. This choice has allowed for a miniaturized and optimized device suitable for field installations. A boost converter has been inserted for compatibility with both 3.3V sensors and 5V sensors. An external dipole antenna has been connected through an RF pigtail to the PCB.

The system supports different agrometeorological sensor types, but in this project, only the following types were taken in consideration:

- Air temperature (T) and relative humidity (RH), air sensor (Sensirion SHT31), protected by a Stevenson shelter in plastic;
- Rain gauge (Pronamic Tower Rain Gauge 1 mm);
- Double-sided capacitive electronic leaf wetness sensor, specifically designed for this project to be low power and low cost (Filipescu *et al.*, 2024), exploiting a capacitance-to-digital converter (FDC2112);
- Soil temperature and moisture sensor (Delta Ohm HD3910.1.A.5)
- Anemometer (Navis WSS100/REED)

For completion, in Table 2 the main metrological characteristics of the used sensors are reported.

All the weather stations have been installed directly inside the vineyards, as shown in Figure 3. The devices have been mounted in the selected field to be as representative as possible of the entire vineyard. Finally, devices have been programmed to take one measurement per sensor at 10-minute intervals, providing 144 daily updates. The transmitted data have been received by LoRaWAN gateways installed in places that have been selected considering the territory characteristics, such as the area dedicated to crops, the altimetric data and exposure characteristic. All locations are strategic from the perspective of electromagnetic propagation but also remain easily accessible for maintenance operations.

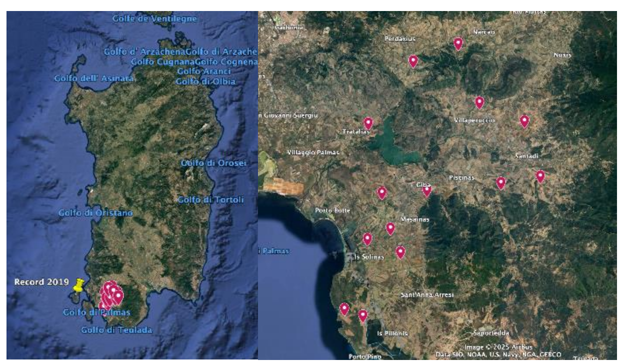

Fig.1 - Location of the analyzed vineyards in South Sardinia (left); map of the area with sensors positions (right)

Fig.1- Ubicazione dell'area oggetto di studio in Sud Sardegna (sinistra); mappa dei sensori con le posizioni dei vigneti interessati dallo studio (destra)

Tab. 2 - Sensors detail as reported in each datasheet
Tab.2 - Caratteristiche dei sensori utilizzati

Sensor	Resolution	Accuracy
Sensirion SHT31	temperature: 0.1 °C RH: 0.1%	temperature: ±0.3 °C RH: ±2%
Leaf Wetness	1%	±5%
Pronamic Tower Rain Gauge	1 mm	±5%
Navis WSS100/REED	1 m/s	±2.5%
Delta Ohm HD3910.1.A.5	temperature: 1°C moisture: 1%	temperature: ±0.5 °C moisture: ±3%

Fig. 3 - Weather stations installed inside the vineyards
Fig.3 - Stazione meteo installata all'interno del vigneto

Plant disease models

Major fungal and oomycete diseases of grapevine have been considered, including well-established as downy mildew and powdery mildew, as well as occasional and emerging diseases such as grey mould and black-rot. For each disease, a systematic literature search focused on the identification of available models has been carried out in Scopus and Web of Science databases. Keywords and search queries have been selected and developed to retrieve predictive models focused on the following criteria: (i) primary infections of downy mildew at the beginning of the season, (ii) ascospore release and primary (ascosporic) infections of powdery mildew at the beginning of the season, (iii) grey mould infections during the season, and (iv) black-rot infections during the season.

Selected models have been translated in R to be connected to meteorological data for model running. Models run on hourly or daily timestep (depending on their requirements) and they provide outputs on a daily basis. Grape growth stage, needed for model running, has been estimated using the IPHEN model (Mariani et al., 2013) fed by weather data collected by the abovementioned network.

Results and Discussion

For each disease, two to four models have been selected among those available in literature (Tab. 3); the choice has been based on their widespread use in major grape-producing regions worldwide.

Concerning the prediction of downy mildew primary infections, models by Orlandini et al. (1993) and Rossi et al. (2008) have been selected. They both provide predictions for primary infection events, with the latter also simulates the dynamic of primary inoculum sources (oospores).

Four models have been selected to predict ascospore release and ascosporic infections of powdery mildew, i.e., the University of California Davis risk index (Gubler et al., 1999) and models by Gadoury and Pearson (1990), Moyer et al. (2014), and Caffi et al. (2011). These models show different degrees of complexity, from simple rules to a mechanistic framework based on *E. necator* life cycle.

Selected models for grey mould include the empirical approach proposed by Broome et al. (1995), which rely on a quadratic equation for infection risk, and two mechanistic models that consider *B. cinerea* life cycle entirely (González-Domínguez et al., 2015) or partially (González-Fernández et al., 2020).

Only two models are available in literature for black-rot, which were therefore selected (Molitor et al., 2016; Rossi et al., 2015). Both have been developed with a mechanistic approach and incorporated key elements in the development of back-rot epidemics as pathogen life cycle and grape susceptibility.

Overall, selected models depict a summary of the different approaches used in model development for grape diseases, as well as different output types, from binary to quantitative, dynamic outputs. This variability in model characteristics allows their comparison under several points of view, mainly differences and similarities in data input and output. In fact, the number of inputs depends on the complexity of the model, with empiric models generally requiring fewer inputs. All selected models require air temperature among inputs, while rainfall, relative humidity, and duration of wetness are differently considered, depending on the approach and the pathogen of interest. It is worth noting that the grape growth stage is considered only in mechanistic models, which embrace a higher level of complexity in the elements of the disease triangle, i.e., pathogen, environment, and host plant.

Tab.3 - Selected models, their developmental approach, working timestep, required inputs, and output type.
Tab. 3 - Modelli selezionati, approccio utilizzato per il loro sviluppo, input richiesti, e tipo di output. Gli acronimi utilizzati per gli input

Name and Reference	**Approach**	**Timestep**	**Input**	**Output**
Downy mildew (*Plasmopara viticola*)				
PLASMO (Orlandini et al. 1993)	Mechanistic	Hour	T, R, RH, WD, GS	Binary
DM-UCSC (Rossi et al. 2008)	Mechanistic	Hour	T, R, RH, WD, GS	Binary/ Numeric
Powdery mildew (*Erysiphe necator*)				
University of California Davis risk index (Gubler et al. 1999)	Empirical	Hour	T, WD	Categoric
Gadoury-Pearson (Gadoury and Pearson 1990)	Empirical	Day	T, R	Binary
Moyer (Moyer et al. 2014)	Empirical	Day	T, R	Binary/ Numeric
PM-UCSC (Caffi et al. 2011)	Mechanistic	Hour	T, R, WD	Numeric
Grey mould (*Botrytis cinerea*)				
Broome (Broome et al. 1995)	Empirical	Hour	T, WD	Categoric
González-Fernández (González-Fernández et al. 2020)	Mechanistic	Hour	T, RH, WD, GS	Numeric
BBR-UCSC (González-Domínguez et al. 2015)	Mechanistic	Hour/Day	T, R, RH, WD, GS	Numeric
Back rot (*Phyllosticta ampelicida*)				
VitiMeteo (Molitor et al. 2016)	Mechanistic	Hour	T, WD, GS	Numeric
BR-UCSC (Rossi et al. 2015)	Mechanistic	Hour	T, R, WD, GS	Numeric

T=temperature (in °C), R= rainfall (in mm), RH= relative humidity (in %), WD = wetness duration (in hours), and GS = grapevine growth stage.
T=temperatura (in °C), R= pioggia (in mm), RH= umidità relativa (in %), WD = durata della bagnatura fogliare (in ore), e GS = fase fenologica della vite.

All selected models work on a daily or hourly basis, to consider a timeframe suitable for biological processes in the development of epidemics. Nevertheless, the hourly time step has been selected to better consider the fluctuations of weather variables during the day, especially when the model included the duration of wetness. In fact, such a variable is often a limiting factor for the development of infections and its correct implementation ensures a higher accuracy in model predictions. In some cases, such as the model for grey mould by González-Domínguez et al. (2015), the model works at two different timesteps (hourly or daily), depending on the considered biological process.
Considering model outputs, empiric models based on rules or simple equations provide results on a binary basis (i.e., yes/no risk of infection) or categorical (i.e., low to high risk). On the other hand, mechanistic or more complex empirical models provide numeric outputs (i.e., scalable values that represent the magnitude of infection occurrence). These outputs provide a more nuanced representation of the reality and may increase the awareness of the user in relation to disease occurrence.
The integration of different models would therefore enable an easier consultation of model output, while comparing their characteristics and, in the future, their performances with real disease occurrence in the field.

Conclusions

Models under comparison are different for the developing approach (empirical vs. mechanistic), the degree of complexity they embed, the number and types of inputs required for their functioning, computational timestep (hourly vs. daily), and produced outputs. Nevertheless, the consultation of several predictive models for main grape diseases, integrated with a well-structured network of weather stations, may cover a key role in the transition towards sustainable viticulture.

Acknowledgments

The authors thank Cantina Santadi sca, in particular Dr. Gianni Poeta, for the fruitful collaboration, granting access to the vineyards and allowing sensors data collection.
This work was supported by the European Union under the Italian National Recovery and Resilience Plan (NRRP) of Next-GenerationEU, partnership on the Agritech National Research Center (NRRP–Mission 4 Component 2, Investment 1.4–D.D. 1032 17/06/2022, CN00000022). This manuscript reflects only the authors' views and opinions; neither the European Union nor the European Commission can be considered responsible for them.

References

Broome J. C., English J. T., Marois J. J., Latorre B. A., Aviles J. C., 1995. Development of an infection model for Botrytis bunch rot of grapes based on wetness duration and temperature. Phytopathology, 85(1), 97-102.

Caffi T., Rossi V., Legler S. E., Bugiani R., 2011. A mechanistic model simulating ascosporic infections by *Erysiphe necator*, the powdery mildew fungus of grapevine. Plant Pathology, 60(3), 522-531

González-Domínguez E., Caffi T., Ciliberti N., Rossi V., 2015. A mechanistic model of *Botrytis ciner*ea on grapevines that includes weather, vine growth stage, and the main infection pathways. PloS one, 10(10), e0140444

González-Fernández E., Piña-Rey A., Fernández-González M., Aira M. J., Rodríguez-Rajo F. J., 2020. Identification and evaluation of the main risk periods of *Botrytis cinerea* infection on grapevine based on phenology, weather conditions and airborne conidia. The Journal of Agricultural Science, 158(1-2), 88-98

Gadoury D. M., Pearson R. C., 1990. Ascocarp dehiscence and ascospore discharge in *Uncinula necator*. Phytopathology, 80(4), 393-401

Gubler W. D., Rademacher M. R., Vasquez S. J., Thomas C. S., 1999. Control of powdery mildew using the UC Davis powdery mildew risk index. APSnet Feature.

Mariani L., Alilla R., Cola G., Monte G. D., Epifani C., Puppi G., Osvaldo F., 2013. IPHEN—a real-time network for phenological monitoring and modelling in Italy. International journal of biometeorology, 57, 881-893.

Molitor D., Augenstein B., Mugnai L., Rinaldi P. A., Sofia, J., Hed B., Beyer M. (2016). Composition and evaluation of a novel web-based decision support system for grape black rot control. European Journal of Plant Pathology, 144, 785-798

Moyer M. M., Gadoury D. M., Wilcox,W. F., Seem R. C., 2014. Release of *Erysiphe necator* ascospores and impact of early season disease pressure on *Vitis vinifera* fruit infection. American Journal of Enology and Viticulture, 65(3), 315-324

Orlandini S., Gozzini B., Rosa M., Egger E., Storchi P., Maracchi G., Miglietta F., 1993. PLASMO: a simulation model for control of *Plasmopara viticola* on grapevine. EPPO Bulletin, *23*(4), 619-626

Rossi V., Onesti G., Legler S. E., Caffi T. 2015. Use of systems analysis to develop plant disease models based on literature data: grape black-rot as a case-study. European Journal of Plant Pathology, 141, 427-444.

Rossi V., Caffi T., Giosuè S., Bugiani R., 2008. A mechanistic model simulating primary infections of downy mildew in grapevine. Ecological modelling, 212(3-4), 480-491