Available on IVES Conference Series vine & wine

DOI : https://doi.org/10.58233/lIQC5xVA

Enhancing vineyard resilience: three years of weather-based disease modeling in Moldova's precision viticulture

Sergiu Smocinschi[1], Vladimir Corobca[2]

[1] Pessl Instruments GmbH, Weiz, Austria
[2] The National Office of Vine and Wine (ONVV), Chisinau, Republic of Moldova

*Corresponding author: sergiu.smocinschi@metos.at

Abstract. Due to ongoing climate change, managing vineyard diseases has become increasingly challenging in the Republic of Moldova. Viticulture, being a strategic agricultural sector in the country, is particularly affected by the unpredictability of weather patterns and the resulting increase in disease pressure. Compounding the issue are the high costs of pesticides, their negative environmental impact, and concerns over grape quality for winemaking, particularly related to chemical residues. Over the last five years, a network of 12 demonstration plots established in commercial vineyards across Republic of Moldova has been used to assess the effectiveness of disease control based on weather monitoring and digital modeling tools. The approach relies on advanced weather stations equipped with sensors that collect real-time agro-meteorological data. These data are integrated into the FieldClimate.com platform to generate disease risk models for key grapevine pathogens. The study has demonstrated that data-driven disease forecasting allows for significant reductions in the number of chemical treatments applied during the growing season, without compromising grape quality or yield. Furthermore, this strategy supports residue minimization and improved compliance with export standards. This experience highlights the importance of adopting precision viticulture technologies to improve sustainability in grape production. Weather-based disease modeling offers a scalable, environmentally friendly approach to vineyard protection, making it a relevant solution for viticulture worldwide in the context of climate change and increasing demand for eco-conscious wine production.

1. Introduction

Viticulture is facing increasingly complex challenges due to climate change, which alters the dynamics of disease development and complicates the timing and effectiveness of grapevine (*Vitis vinifera*) plant protection strategies. Among the most critical issues in modern grapevine production are fungal diseases such as downy mildew *Plasmopara viticola* and powdery mildew (*Erysiphe necator*), both of which are strongly influenced by weather conditions throughout the growing season [1, 2].

In the Republic of Moldova, where viticulture represents a strategic agricultural and economic sector, these challenges are exacerbated by rising pesticide costs, environmental concerns, and the growing demand for high-quality grapes suitable for winemaking. The accumulation of chemical residues on grapes also poses risks to wine production potential and consumer safety. Furthermore, the environmental burden associated with traditional calendar-based spraying schedules necessitates a transition towards more sustainable and efficient plant protection practices.

The advent of digital tools and precision agriculture technologies has opened new avenues for viticultural disease management. Among these, weather-based disease modeling using agrometeorological stations installed in vineyards has proven to be a promising approach. Such systems enable dynamic risk assessment for pathogen development and support growers in optimizing fungicide application timing [3, 4]. In particular, the FieldClimate platform by Pessl Instruments integrates real-time meteorological data with mechanistic models to simulate disease pressure and forecast infection windows for key pathogens.

Despite the availability of various predictive models across Europe, there is a lack of field-based validation studies from Eastern European countries such as Republic of Moldova. In response, the National Office for Vine and Wine (ONVV) launched a demonstration project in 2021 across 12 commercial vineyards to evaluate the practical effectiveness of weather-based disease forecasting in reducing fungicide use and enhancing sustainability in viticulture.

The objective of this study is to assess the effectiveness of weather-driven disease modeling tools in managing grapevine diseases in Republic of Moldova, by analyzing the impact on treatment frequency, disease incidence, and grape quality under commercial conditions.

2. Materials and Methods

2.1. Experimental sites and monitoring system

This study was conducted from 2021 to 2024 across twelve commercial vineyards located in the main viticultural zones of the Republic of Moldova, covering all three official Protected Geographical Indication (PGI) regions: Codru, Ștefan Vodă, and Valul lui Traian. These regions represent diverse climatic and soil conditions and are responsible for the majority of the country's high-quality grape and wine production.

Each vineyard was equipped with an iMETOS® IMT300 weather station (Pessl Instruments GmbH, Austria), installed in the center of the plot to ensure optimal measurement of microclimatic conditions [5]. All stations were identically configured and equipped with sensors for measuring air temperature, relative humidity, leaf wetness duration, rainfall, soil temperature, soil moisture, and solar radiation. Meteorological data were recorded and transmitted automatically to the FieldClimate.com platform at a resolution of one hour, enabling hourly updates of disease risk models [6].

2.2. Disease risk modelling

Disease development risks were evaluated using integrated predictive models available on the FieldClimate platform (**Figure 1**). For grape downy mildew *Plasmopara viticola*, the system applied a weather-driven model that predicts primary and secondary infections based on thresholds of leaf wetness duration and temperature [1,7]. For grape powdery mildew (*Erysiphe necator*), the UC Davis Powdery Mildew Risk Index was used, which dynamically calculates disease risk based on environmental conditions including temperature and relative humidity [2,4].

These predictive models provided an efficient and practical tool for optimizing treatment timing, allowing for preventive applications before visible symptoms occurred. This proactive approach significantly improved protection efficacy while minimizing unnecessary chemical use.

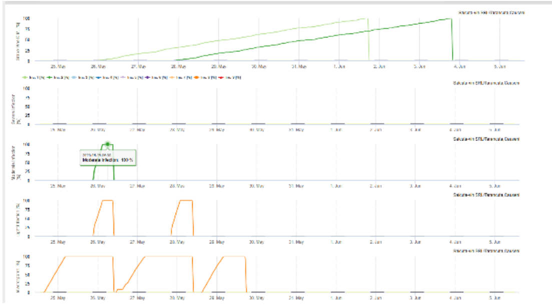

Figure 1. Hourly updated disease risk levels for *Plasmopara viticola* shown in the FieldClimate platform. The model displays cumulative infection risk and individual infection event probabilities (light, moderate, severe), allowing real-time decision-making for preventive treatments.

Each model generated infection risk alerts that were updated hourly, allowing near real-time disease monitoring and decision-making.

2.3. Treatment decision protocol

Fungicide applications were conducted only when disease models indicated moderate or high infection risk levels. Treatments were primarily preventive, targeting predicted infection windows before visual symptoms appeared. No treatments were applied based on a pre-defined calendar schedule. Instead, all interventions strictly followed the recommendations generated by the hourly updated disease risk models.

The number of fungicide applications and the amounts used were systematically recorded throughout the growing seasons, based on standardized field protocols developed within the national demonstration project [8].

2.4. Data collection and analysis

Throughout the monitoring period, data were systematically collected from each of the twelve demonstration plots. The primary parameters tracked included the number of fungicide treatments applied during the growing season, the timing of each intervention, and the disease risk level as predicted by the corresponding models at the moment of application. Weather data were continuously recorded and updated every hour, enabling a fine-grained correlation between infection risk evolution and treatment decisions. Observational data from the field teams were also recorded, including phenological stages, visual presence or absence of disease symptoms, and relevant vineyard management activities.

For each season, the number of treatments applied under the model-guided approach was compared with historical data from previous years when conventional calendar-based spray schedules had been followed in the same vineyards. Although not the focus of this section, it is important to note that all quantitative and comparative analyses were performed at the end of each season and will be further discussed in the results. Additionally, meteorological anomalies or unusual patterns were noted, particularly during key infection risk periods, to support the interpretation of disease model performance. These data allowed us to evaluate not only the decision accuracy of the disease models, but also their practical impact on the reduction of chemical use and overall treatment intensity.

The monitoring framework was designed to reflect real-world vineyard management conditions, ensuring that the observations and treatment data collected represent practical applications of precision viticulture, rather than experimental conditions in controlled environments.

3. Results

Over the three-year monitoring period (2022–2024), the application of weather-based disease models in 12 commercial vineyards across Republic of Moldova resulted in a significant reduction in the number and volume of fungicide treatments applied, without compromising grape quality or disease control efficacy. Compared to the average treatment frequency and spray volume used in traditional calendar-based schedules, vineyards applying model-guided interventions reduced treatments by approximately 20% to 35%, depending on seasonal disease pressure and climatic conditions [8].

As illustrated in Figures 2–4, the number of fungicide applications targeting *Plasmopara viticola* and Erysiphe necator was consistently lower across all demonstration plots in each year. This reduction was achieved by timing treatments in response to real-time infection risk forecasts generated hourly by the FieldClimate platform using iMETOS stations [5,6]. For downy mildew, the FieldClimate model used the hourly criteria of leaf wetness >30 min, RH >80%, and temperature between 10°C and 30°C to predict sporulation and infection risk [1,3,7]. For powdery mildew, the Gubler-Thomas risk index was applied, incorporating temperature-based thresholds to quantify disease pressure [2].

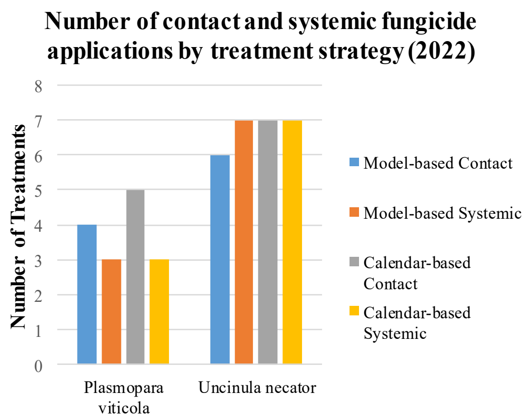

Figure 2. Comparison of Model-Based and Calendar-Based Fungicide Treatments per Pathogen in 2022. The chart displays the number of contact and systemic fungicide applications for *Plasmopara viticola* and *Uncinula necator* under model-based vs calendar-based strategies.

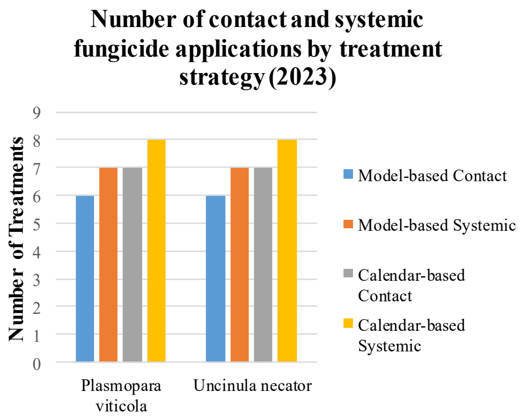

Figure 3. Comparison of Model-Based and Calendar-Based Fungicide Treatments per Pathogen in 2023. Year with increased disease pressure, requiring more treatments, but still showing model-driven reduction in chemical use.

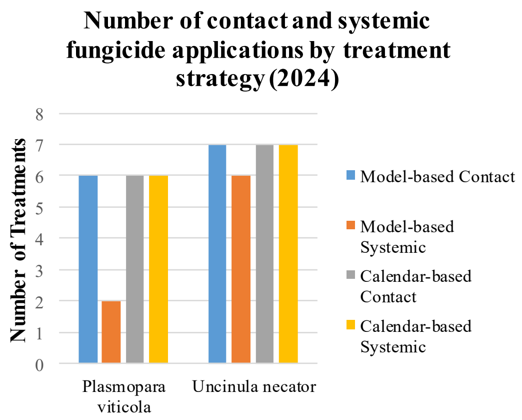

Figure 4. Comparison of Model-Based and Calendar-Based Fungicide Treatments per Pathogen in 2024. The model-based approach led to a significant reduction of systemic fungicides for *Plasmopara viticola*, while maintaining consistent results for *Uncinula necator*.

The reduction in treatments was particularly effective during seasons with intermittent disease pressure, when traditional programs would have led to unnecessary applications. In high-pressure years such as 2023, the system still allowed for timely interventions, demonstrating its robustness and adaptability. The hourly resolution of model updates enabled rapid decision-making and adaptation to local microclimatic conditions, offering a clear advantage over calendar spraying.

These results validate the practical applicability of precision viticulture tools in Republic of Moldova's wine sector and confirm that data-driven disease management can significantly reduce environmental impact and production costs while maintaining crop health.

4. Discussion

The comparative analysis of model-based and calendar-based treatments across three consecutive seasons (2022–2024) demonstrated that precision viticulture practices relying on weather-driven disease models can substantially optimize fungicide use in commercial vineyards in Moldova. Particularly for *Plasmopara viticola*, the implementation of model-supported decisions led to a consistent reduction in the total number of treatments, especially in 2022 and 2024, when contact and systemic fungicides were applied more selectively, guided by the infection risk output from the FieldClimate platform models [1,6].

In 2022, model-guided treatments for *Plasmopara viticola* required only 4 contact and 3 systemic applications, compared to 5 and 3 respectively under calendar-based strategies. A similar trend persisted in 2024, where systemic treatments dropped significantly to 2 (Figure 2), suggesting that risk-adaptive approaches can effectively prevent overuse of fungicides. These results align with findings from Brischetto et al. [1] and Caffi et al. [4], who reported comparable reductions in Mediterranean trials using disease forecasting systems.

For *Uncinula necator*, treatment frequencies remained relatively constant across both treatment schemes, highlighting the need for further model refinement or integration with additional indicators (e.g., canopy microclimate, resistance data). While the Gubler Risk Index has shown strong predictive capacity in Californian vineyards [2], local validation and customization may be needed for Eastern European climates to yield similar benefits.

The 2023 season stands out with a minimal difference between treatment schemes, indicating higher disease pressure and a reduced opportunity for differentiation between model-based and conventional calendars. This is in agreement with Puelles et al. [3], who emphasized that DSS performance is context-dependent and influenced by seasonal climatic variability.

In general, model-driven strategies enhanced the sustainability of disease management by minimizing unnecessary applications. Besides reducing costs, this also lowers environmental load and mitigates fungicide resistance—a critical point stressed by recent reviews on DSS integration in viticulture [1,7]. The results also support internal monitoring data from the ONVV project reports [8], which estimated annual reductions of 20–35% in total fungicide usage in the monitored demo plots.

These findings validate the importance of localized DSS adaptation and the utility of hourly-resolved model data, especially under Republic of Moldova's increasingly variable weather conditions. Continuing this monitoring over additional seasons will provide more robust insights into long-term efficacy, model calibration needs, and scalability potential for broader adoption.

5. Conclusions

The integration of weather-based disease models into vineyard management in Republic of Moldova has demonstrated clear benefits over calendar-based fungicide applications. Over three consecutive growing seasons (2022–2024), the implementation of model-guided treatments allowed for a reduction of 20–35% in the number and volume of fungicide applications without compromising disease control or grape quality. This was especially evident for *Plasmopara viticola*, where systemic fungicides were applied more selectively and effectively based on model outputs.

These results highlight the value of precision viticulture practices in enhancing the sustainability of grape production. By aligning disease management decisions with real-time weather data and pathogen development models, growers can reduce environmental impact, lower production costs, and contribute to a more resilient viticultural system.

Moreover, the findings support the broader relevance of DSS tools like the FieldClimate platform in viticultural regions facing increasing climate variability. Continued application and refinement of such models will be essential for adapting to future disease pressures while maintaining productivity and environmental stewardship.

6. Acknowledgements

This work was carried out within the framework of the national program on precision viticulture, coordinated by the National Office for Vine and Wine (ONVV) in the Republic of Moldova during 2021–2024. The authors would like to thank ONVV for their continuous support and collaboration, especially Dr. Vladimir Corobca, Coordinator of Viticulture at ONVV, for his valuable guidance and expertise throughout the project. We also express our gratitude to the partner vineyards for providing access to their fields and operational data. Special thanks are extended to the technical teams involved in data collection, treatment application, and local validation. The implementation of disease models was made possible through the use of the FieldClimate platform, provided by Pessl Instruments GmbH.

7. References

1. Brischetto C., Bove F., Fedele G., Rossi V. A Weather-Driven Model for Predicting Infections of Grapevines by Sporangia of *Plasmopara viticola*. Front. Plant Sci. 12, 636607 (2021).

2. Gubler W.D. Biology, Epidemiology, and Control of Powdery Mildew: Use of the UC Davis Powdery Mildew Risk Index. UC Davis Plant Pathology (2012).

3. Puelles M., et al. Predictive models for grape downy mildew (*Plasmopara viticola*) as a decision support system in Mediterranean conditions. Crop Prot. 165, 106450 (2023).

4. Caffi T., Rossi V., et al. A mechanistic model simulating ascosporic infections by Erysiphe necator, the powdery mildew fungus of grapevine. Plant Pathol. 60(3), 522–531 (2011).

5. Pessl Instruments GmbH. iMETOS Weather Stations – Technical Specifications (2020).

6. FieldClimate.com. FieldClimate Platform – Data Processing and Model Integration Manual (2022).

7. Caffi T., Rossi V., Legler S.E., Bugiani R. A model predicting primary infections of *Plasmopara viticola* in different grapevine-growing areas of Italy. J. Plant Pathol. 90, 61–72 (2008).

8. National Office for Vine and Wine (ONVV), Republic of Moldova. Annual Project Reports 2021–2024 on Precision Viticulture and Sustainable Disease Management (internal reports).