

Why aren't farmers using precision viticulture frequently? AGRARIAN case study as a model

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Abstract

In the last years, viticulture precision tools have been made available for farmers for different crops. The feeling that these tools are mandatory on an agriculture of the future have been disseminated by commercial entities but also from policy makers. However, the amount of data and the difficulty by farmers to understand it, lead to avoidable expenses and frustration. Maybe driven by past video games, it's expected that in the future all practices, decisions and operations will be done by machines and farmers will only be watch. It's true that these data could help analysing the plot and, in some case, could provide help on achieving better results, but most of the farmers don't understand this information and the lack of extension services just brings more difficulty on the establishment of these tools. In addition, some of the models don't consider different susceptibilities to grapevine varieties, soil type, training method or historical data. In all tools and models, a field validation should always be done to correct and set a better decision support system.

AVIPE is involved in AGRARIAN EU project where precision viticulture tools are tested for irrigation and yield estimation and where validation is crucial on achieving good results. Results have showed a problem on the model to understand grapevine varieties. Moreover, it was a clear a difficulty on relating satellite images and water status data collected by pressure chamber.

Keywords: AGRARIAN, precision viticulture farmers

Introduction

Precision agriculture technologies are increasingly promoted as key tools for improving efficiency, sustainability, and decision-making in modern farming systems. In viticulture, the rapid expansion of digital platforms, satellite-based monitoring, and predictive models has generated new opportunities for vineyard management. However, despite their growing availability, many farmers face significant challenges in interpreting and applying the large volumes of data produced by these technologies. The complexity of digital tools, combined with limited technical support and extension services, often results in uncertainty regarding their real benefits and may lead to unnecessary investments or frustration among growers. This situation raises an important question: to what extent do current precision viticulture tools effectively support vineyard management decisions under real field conditions?

This study addresses the practical problem of evaluating the applicability and reliability of precision viticulture tools when implemented in commercial vineyards. While digital models promise improved monitoring of crop status and more accurate predictions of yield or water requirements, their performance often depends on local agronomic conditions that may not be fully represented in algorithm development. Factors such as grapevine variety, soil characteristics, training systems, and historical vineyard management practices can significantly influence plant behaviour and therefore affect the accuracy of model outputs. In many cases, existing tools do not sufficiently account for this variability, highlighting the need for systematic validation using field data.

Within this context, the present research investigates the performance of precision viticulture

technologies tested under the framework of the AGRARIAN EU Project, specifically within Pilot 3 dedicated to vineyard management. The project focuses on the application of digital tools for irrigation management and yield estimation, two critical aspects of vineyard productivity and sustainability. The research analyses how these tools interpret vineyard variability and evaluate their capacity to support practical decision-making in vineyard operations.

The study particularly examines the relationship between satellite-derived data and direct physiological measurements of grapevine water status, as well as the ability of predictive models to accurately estimate yield across different vineyard conditions. Data collected through remote sensing platforms are compared with ground-based measurements obtained using pressure chamber techniques to assess the consistency and reliability of digital indicators. This comparison allows the identification of potential discrepancies between model predictions and actual plant responses.

Results highlight several limitations that affect the practical use of these technologies. The analysis reveals that some predictive models struggle to correctly account for differences among grapevine varieties, which can significantly influence vine vigour, productivity, and water requirements. The study also identifies difficulties in establishing consistent correlations between satellite imagery indicators and grapevine water status measured directly in the field. These discrepancies indicate that certain models may oversimplify vineyard variability, reduce their effectiveness when applied in heterogeneous production systems.

The research therefore evaluates the importance of field validation in improving the reliability of precision viticulture tools. By analysing the performance of digital models under real vineyard conditions, the study contributes to a better understanding of their current limitations and identifies areas where further refinement is necessary

Data and Method

The yield estimation and irrigation management framework developed by GAMAYA is based on machine learning models designed for crop yield forecasting and soil moisture prediction. These models are trained using historical agricultural datasets and, where available, *in situ* soil moisture sensor measurements. The predictive framework integrates multisource data, including satellite-derived vegetation indices, meteorological information, and domain-specific agricultural knowledge, to generate accurate forecasts for crop performance and irrigation requirements.

To support crop monitoring and water management, the system employs several vegetation indices derived from satellite imagery, including the Normalized Difference Vegetation Index (NDVI), Normalized Difference Red Edge (NDRE), Normalized Difference Water Index (NDWI), Normalized Difference Moisture Index (NDMI), and the Enhanced Vegetation Index (EVI). These indices provide critical information regarding crop vigor, chlorophyll activity, canopy structure, and plant water status, thereby enhancing the predictive capability of the machine learning models.

The data processing workflow involves continuous model refinement through the integration of newly acquired environmental data. Following the initial training phase on historical datasets, the GAMAYA monitoring platform updates and adjusts forecasts on a weekly basis using the most recent satellite imagery and weather observations. This iterative updating process enables the system to account for changing environmental conditions and improves the temporal accuracy of yield estimation and soil moisture predictions.

For the implementation of Pilot 3, the study area comprised approximately 1,500 hectares

distributed across 82 farmers located in the Península de Setúbal wine region in Portugal. The dataset used for model development and validation included information on crop yield, historical pest and disease pressure, soil organic matter, irrigation blocks, and grapevine varieties. Data were collected directly from participating farmers as well as from analyses provided by AVIPE.

Results

The performance of the machine learning framework was quantitatively evaluated using historical observations collected between 2019 and 2024. The dataset comprised 853 agricultural field measurements obtained from vineyards located across the southern region of Portugal. The monitoring period covered the grapevine growing season from May to September for each production year. Yield measurements were recorded after harvest completion and expressed in tons per hectare (t/ha) at the individual field level.

The yield prediction model was assessed using a leave-one-year-out cross-validation approach over the 2019–2024 period to ensure temporal robustness and generalizability across growing seasons. The model achieved a mean prediction error of 4.63%, with a standard deviation of 3.10%, indicating stable predictive performance across different years and environmental conditions. In addition, the soil moisture prediction component demonstrated an average prediction error of approximately 15%.

The disease and pest detection models also demonstrated high classification accuracy across multiple vineyard stress factors. The downy mildew detection model achieved an accuracy of 94.54%, while the powdery mildew model reached 91.57%. Pest monitoring models showed accuracies of 97.7% for green leafhopper detection and 94.87% for grapevine moth detection. Furthermore, the sunburn detection model achieved an accuracy of 94.25%. These results indicate the strong capability of the integrated monitoring system to support precision viticulture applications through reliable disease, pest, and environmental stress assessment.

Table 1: Performance Metrics of the Predictive Models.

Model Component	Evaluation Metric	Performance
Yield Prediction	Mean Error	4.63%
Yield Prediction	Standard Deviation of Error	3.10%
Soil Moisture Prediction	Prediction Error	15%
Downy Mildew Detection	Accuracy	94.54%
Powdery Mildew Detection	Accuracy	91.57%
Green Leafhopper Detection	Accuracy	97.7%
Grapevine Moth Detection	Accuracy	94.87%
Sunburn Detection	Accuracy	94.25%

The spatial distribution of the monitored fields encompassed multiple vineyard plots within the Península de Setúbal wine region and other vineyard areas in southern Portugal. Data collection was conducted continuously throughout the growing season using satellite observations, weather information, field records, and agronomic analyses. This combination of temporal and spatial coverage enabled the development of robust predictive models capable of capturing interannual variability and localized vineyard conditions.

The evaluation of precision viticulture tools within Pilot 3 of the AGRARIAN EU Project revealed several important findings regarding the reliability and applicability of digital

decision-support systems for vineyard management. The analysis focused primarily on irrigation management and yield estimation through the integration of satellite-derived observations and ground-based measurements collected from commercial vineyard plots.

The results demonstrated that predictive models for yield estimation exhibited variable performance depending on the grapevine variety. While the models generated acceptable estimations in several vineyard plots, substantial deviations were observed in others where varietal characteristics strongly influenced vine vigour and productivity dynamics. These findings suggest that the current algorithms do not fully account for the physiological and agronomic variability among grapevine cultivars. Consequently, prediction accuracy decreased in vineyards containing multiple grapevine varieties or specific training systems.

The comparison between satellite-derived vegetation indicators and direct field measurements of vine water status also highlighted several limitations. Vegetation indices extracted from satellite imagery successfully captured general patterns of canopy vigour and spatial variability within vineyard plots. However, the correlation between these indices and vine water status measurements obtained using pressure chamber techniques remained inconsistent. In several cases, vineyard areas presenting similar spectral responses and vegetative activity exhibited substantially different levels of water stress under field measurements. These observations indicate that canopy reflectance alone may not adequately represent the physiological condition of grapevines under varying environmental conditions.

Another important finding concerned the temporal variability of vineyard conditions during the growing season. Although satellite imagery provided periodic assessments of canopy development, rapid environmental changes and irrigation events were not always immediately reflected in the satellite observations. This temporal mismatch reduced the ability of the predictive models to generate highly precise irrigation scheduling recommendations at specific moments during the production cycle. The results therefore emphasize the importance of integrating satellite monitoring with higher-frequency ground observations and field-based measurements to improve the responsiveness and reliability of precision irrigation management systems.

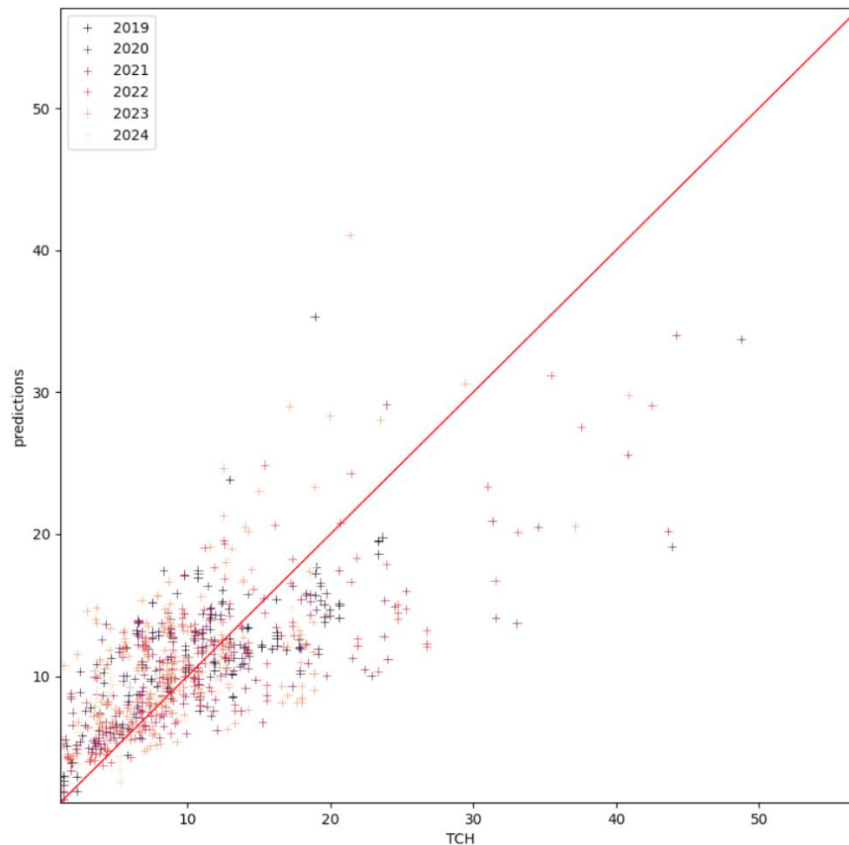


Figure 1: Correlation plot.

Conclusion

The results obtained within Pilot 3 highlight that the effectiveness of precision viticulture tools depends not only on technological accuracy, but also on the capacity to transform data into practical and context-specific decision support for farmers. The adoption of digital agricultural technologies requires stronger integration between technological innovation, local knowledge, and advisory support services.

Several improvements can enhance the reliability and applicability of precision viticulture tools. First, predictive algorithms should incorporate grapevine varietal characteristics, training systems, and local agronomic practices to better capture vineyard heterogeneity. The integration of higher-frequency field measurements, such as soil moisture sensors and physiological plant indicators, would improve the calibration of satellite-derived models and reduce inconsistencies between remote sensing observations and field conditions. Additionally, increasing temporal resolution through more frequent satellite acquisitions or complementary drone imagery could improve irrigation recommendations during rapidly changing environmental conditions.

Advisory and extension services should play a central role in facilitating the adoption of precision viticulture technologies. As highlighted in the AVIPE experience, digitalization alone is insufficient if solutions are not adapted to farmers' operational realities and technical capacities. Advisory services should therefore function as intermediaries between technological providers, researchers, and farmers by supporting data interpretation, promoting digital literacy, and validating recommendations under local vineyard conditions. Human expertise remains essential to contextualize algorithmic outputs and strengthen farmer confidence in decision-support systems.

To improve the adoption of precision viticulture tools, future strategies should prioritize farmer training, interoperable data platforms, and the co-development of technologies with end users. Public and private institutions should invest in integrated monitoring infrastructures that combine satellite data, field observations, and advisory support. Furthermore, participatory approaches involving growers throughout the development process can improve usability, transparency, and trust, ultimately increasing the practical value and long-term adoption of digital viticulture solutions.