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DECISION-SUPPORT SYSTEM FOR WATER STRESS ASSESSMENT AND DEFICIT IRRIGATION MANAGEMENT IN WINE GRAPES

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Extended Abstract

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1. Chapter 1: Introduction

Regulated deficit irrigation (RDI) is an irrigation management strategy which applies less water than the full water requirement in some growing phases (e.g., from fruit set to veraison) to achieve a mild to moderate water stress. The implementation of RDI in wine grape production requires a combination of crop physiological knowledge, accurate assessment and monitoring of crop water status, and effective decision-making to achieve the desired balance between water stress and adequate water availability to the plants. For site-specific RDI scheduling, it is essential to develop ground-based approaches that provide detailed information on grapevine water status, taking into account the vine canopy architecture. An RDI scheduling system incorporating dynamic water stress thresholds is needed to support decision-making in managing water stress throughout the various growth stages of grapevines. This research aimed to develop and validate a comprehensive decision-support system for precision RDI management in vineyards. The proposed system used ground-based hyperspectral imaging to accurately assess soil and plant water status, along with an irrigation scheduling model to forecast ideal weekly irrigation volumes. This framework is vital for automating site-specific irrigation and balancing yield and quality in wine grape production, ensuring the industry's long-term sustainability.

2. Chapter 2: Estimating Soil and Grapevine Water Status Using Ground-Based Hyperspectral Imaging under Diffused Lighting Conditions

A timely and appropriate level of water deficit is desirable in wine grape production to optimize fruit quality for winemaking. Thus, it is crucial to find a robust and rapid method to assess grapevine water stress in real time. Hyperspectral imaging (HSI) has the potential to detect changes in leaf water status, but the robustness and accuracy are limited in field applications. This study focused on developing practical approaches for detecting soil and grapevine water status using ground-based HSI obtained in diffused light conditions. During the 2021 growing season, leaf water potential (Ψ_L), stomatal conductance (gs) on the selected leaves and volumetric soil moisture (θ_v) in the root zone were measured as water status indicators. Spectral data from diffused and direct sunlight conditions were obtained to construct models to estimate plant and soil water status indicators. Partial least squares (PLS) regression models were individually developed to estimate Ψ_L, gs, and θ_v using spectra obtained from direct/diffused light conditions. The results indicated that the Ψ_L estimation model using spectral data from diffused lighting performed better than the same obtained using direct sunlight, indicated by a higher R^2 (0.89 vs. 0.82), a lower RMSE (0.12 vs. 0.15 MPa) and a lower MAE (0.10 vs. 0.11 MPa). The model developed for estimating θ_v using spectral data under diffused light achieved superior performance compared to the one in direct sunlight in terms of R^2, RMSE and MAE (0.90 vs. 0.89, 1.56 % vs. 1.59 %, and 1.26 % vs. 1.29 %). These results demonstrated that spectral data obtained under diffused light can slightly improve model performance by providing a more uniform illumination. The ground-based hyperspectral imaging approach offered a promising solution for the high-resolution sensing of grapevine water status, capturing variability within canopies with detailed information, which could benefit both viticulture research and commercial vineyard management.

3. Chapter 3: Estimating Grapevine Water Status Through Fusion of Hyperspectral Image and 3D Point Clouds

As discussed before, mild to moderate and timely water deficit is desirable in grape production to optimize fruit quality for winemaking. It is crucial to develop robust and rapid approaches to assess grapevine water stress for scheduling deficit irrigation. Hyperspectral imaging (HSI) has the potential to detect changes in leaf water status, but the robustness and accuracy are restricted in field applications. One of the major reasons for this challenge is the varied leaf orientations that can affect how light interacts with the plant, ultimately influencing the reflectance recorded by HIS. This study focused on developing an approach for reliably detecting grapevine water status using HSI and 3D data. Leaf orientation parameters derived from 3D point clouds were integrated with spectral signatures to minimize the spectral variance caused by variations in leaf orientation. Using these parameters, a water status assessment model was developed based on multiblock partial least squares (MBPLS) to estimate leaf water potential (Ψ_L). HSI and 3D point clouds of selected leaves were captured simultaneously in a vineyard during the 2021 growing season, and Ψ_L was measured as the groundtruth to assess the model performance. Mean spectral reflectance was derived from the hyperspectral images, while leaf orientation parameters were extracted from 3D point cloud data. The dataset was split randomly into 70 % training/calibration and 30 % test datasets. The test result shows that the model estimated the Ψ_L with an R^2 of 0.89, RMSE of 0.12 MPa and MAE of 0.09 MPa. The leaf orientation parameters derived from 3D point clouds had a contribution of 6.25 % in estimating Ψ_L, which acted as an enhancing component that explained the spectral variance caused by variations in leaf orientation and improved the interpretation of the underlying relationship between spectral reflectance and vine water status.

4. Chapter 4: Incorporating Dynamic Soil Moisture Thresholds into Regulated Deficit Irrigation Scheduling

As discussed before, deficit irrigation is often used in the wine grape industry to balance grape yield for optimizing fruit quality for winemaking. Regulated deficit irrigation (RDI) technique is used to apply less water than the full water requirement in some growing phases. This study focused on developing a decision-support system for managing precision RDI in vineyards. The system consists of a soil moisture prediction model and an RDI scheduling model developed using an artificial neural network. Initial soil moisture, weather variables, crop coefficient, and irrigation amount were used as inputs to the soil moisture prediction model. The output from this prediction model provided an indicator of future water status in soil and vines. Initial soil moisture, weather variables, crop coefficient and desired soil moisture target were used as inputs to the RDI scheduling model for regulating the amount of water applied to achieve a desired soil moisture target which is linked to the grapevine water stress target. Field data were collected weekly during the 2017 to 2021 growing seasons. Data from the first four seasons (2017-2020) was used to train the models, and the 2021 data was used to test the system's performance. Validation test results showed that the soil moisture prediction model could predict the soil moisture in the following week with an R^2 of 0.93 and RMSE of 0.86 %, and the RDI scheduling model could estimate the weekly irrigation water amount for maintaining a target soil moisture with an R^2 of 0.94 and RMSE of 8.85 L per drip irrigation emitter. The results demonstrated that this system was capable of predicting the "following-week" soil moisture changes and creating an adequate weekly drip irrigation plan for controlling the soil moisture at desired levels. This system has the potential to be a useful practical tool for managing RDI in vineyards with the aim of achieving the production goal of balanced yield and optimized fruit quality.

5. Chapter 5: Conclusions and Recommendations

This study focused on developing and validating a decision-support system for precision regulated deficit irrigation (RDI) management in vineyards. The system employed ground-based hyperspectral imaging (HSI) and stereo vision to provide accurate assessments of soil and plant water statuses. Concurrently, the RDI scheduling component of the system forecasted optimal weekly irrigation amounts necessary to keep soil moisture within predefined thresholds. Future studies could explore: (1) the integration of deficit irrigation systems with weather forecasting to better manage uncertainties in weather conditions; and (2) the development of tools for sequential decision-making that adjust irrigation based on real-time monitoring of grapevine water status.

Final remarks concerning benchmarks and strength points of the the Pellizzi Prize 2024

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This research aimed at developing and validating a comprehensive decision-support system for precision RDI management in vineyards. The proposed system employed ground-based hyperspectral imaging (HSI) to accurately assess soil and plant water status. Concurrently, a RDI scheduling model was developed which forecasted the ideal weekly irrigation volumes needed to maintain soil water content within predefined thresholds. Collectively, these subsystems comprise a comprehensive decision-support framework, aiding human decision-making in vineyards. This framework is suitable for developing a practically adoptable system for automated, site-specific irrigation and balancing of yield and quality in wine grape production. When commercially adopted, this technology has a potential to substantially minimize water use while maximizing crop yield and quality in vineyards.