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A Novel Low-Cost System for *Xylella fastidiosa* Early Detection Using Electrical Conductivity Probes †

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Abstract: *Xylella fastidiosa* is a devastating pathogen that has significantly impacted olive cultivation, particularly in Southern Italy, since 2013. Monitoring and early identification are crucial for managing the spread of this disease and minimising associated economic losses. This study presents a low-cost system employing electrical conductivity (EC) probes to monitor the water status of olive tree stems, enabling the early detection of *X. fastidiosa*. The system provides real-time data by detecting changes in EC, which are possibly correlated with the presence of the pathogen. In contrast to traditional detection methods like PCR, which are expensive and require laboratory facilities, this system offers a practical, field-deployable, and sustainable solution. In a testbed, EC probes were installed on an olive tree in Southern Italy, with data transmitted via a GSM network to a central server for analysis. Powered by solar energy, the system successfully detected changes in the stem's water content, which were subsequently confirmed to be associated with pathogen presence. This low-cost EC probe system initially demonstrates promising potential for the early detection of *X. fastidiosa*, enabling proactive management strategies. Future research will focus on improving the system's sensitivity and conducting extensive field trials across diverse environments and applications.

Keywords: *Xylella fastidiosa*; low-cost sensors; early warning; signal analysis

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1. Introduction

The bacterial pathogen *X. fastidiosa* has been recognised as a significant phytopathogenic agent, causing widespread devastation across diverse plant species globally. The early detection of this pathogen is pivotal for the implementation of control measures to mitigate its spread and to minimise economic losses. However, the existing diagnostic methods are either too intricate and expensive for routine surveillance or lack the necessary sensitivity for early-stage detection. To address these challenges, this study presents the development of a low-cost, accessible system based on EC probes for the early detection of *X. fastidiosa*. The system exploits the disruption of xylem fluid conductivity caused by bacterial infection, providing a quantifiable measure that correlates with the presence of the pathogen. The proposed system is grounded in the key symptom of rapid desiccation in olive trees, as previously highlighted by Saponari et al. in their work on Olive Quick Decline Syndrome [1]. The simplicity of the approach allows for rapid, in-field diagnostics without the need for specialised laboratory equipment or expertise. By integrating the principles of electrical engineering with plant pathology, this system offers a promising solution for the early-stage detection of *X. fastidiosa*, aiming to significantly reduce the time and resource burden associated with current testing methods. The paper will detail the design and development process, calibration, and field testing of the EC probes, demonstrating their effectiveness in early pathogen detection and their potential role in precision agriculture and plant disease management.

Motivation and Contribution

Considering the importance of olive cultivation for Mediterranean countries [2], there is a necessity to establish comprehensive infrastructures devoted to monitoring, researching, and managing *X. fastidiosa*. This proactive approach is vital for protecting the vast olive groves that make significant contributions to both local and national economies. Building such infrastructures could set a precedent for agricultural preparedness, ensuring readiness and effective response if the pathogen were to spread into Greek territories. Preserving these crops is not only essential from an economic standpoint but also crucial for maintaining a cultural heritage that has thrived in Greece and all Mediterranean countries for millennia [2–4]. Immediate and decisive action must be taken to preserve the tradition of olive cultivation for future generations.

The primary goal was to create a low-cost monitoring system capable of tracking the stem water of olive trees by installing probes in various branches, establishing very dense networks for areas under pressure. As previously stated, a key symptom of *X. fastidiosa* is OQDS, which leads to the rapid drying of the tree. Monitoring stem water serves as a critical indicator of the tree's health, making it an essential measurement. Consequently, the proposed low-cost system has been designed for every cultivator to assess fluid levels within their trees' trunks or branches almost in real time. The primary contribution of this paper can be summarised as follows:

- Proof of concept of the low-cost and early warning system for OQDS;
- Development and pilot installation in the olive grove;
- Almost real-time data collection via GSM network;
- An innovative solution for cultivators.

2. Background and Related Work

X. fastidiosa was initially documented in the Americas in 1982 by Newton Pierce, leading to significant issues for vineyards in California at that time [5]. As Figure 1 illustrates, the recently updated global map indicates the infection is primarily found in North and South America, with references to Europe being notably significant [6]. Since its emergence in South Italy in October 2013 [7], scientists from various fields have been diligently studying the pathogen to gain a comprehensive understanding.

One of the most significant symptoms of the *X. fastidiosa* is the pathological condition Olive Quick Decline Syndrome (OQDS), which causes quick olive tree drought [1]. Thus, stem water monitoring is a crucial indicator of the tree's health and, in advance, *X. fastidiosa*. The main idea of the proposed low-cost system in this work is to measure this symptom almost in real time. Matheny et al. calibrated and installed capacitance soil moisture sensors in order to monitor the stem's water levels [8]. In the same way, Saito et al., in 2016, used soil moisture sensors to calculate the stem water content in arid environments [9]. Therefore, technological improvement provides in situ monitoring of stem water content, even with non-invasive methods such as Cheng et al.'s innovation [10]. Two different past works used a different perspective for early detection of *X. fastidiosa*, combining UAV multispectral imagery, machine learning techniques, and GIS environment [11,12]. Morelli et al. emphasise that additional work is still required to deliver a thorough and lasting solution, notwithstanding the efforts of various projects [13].

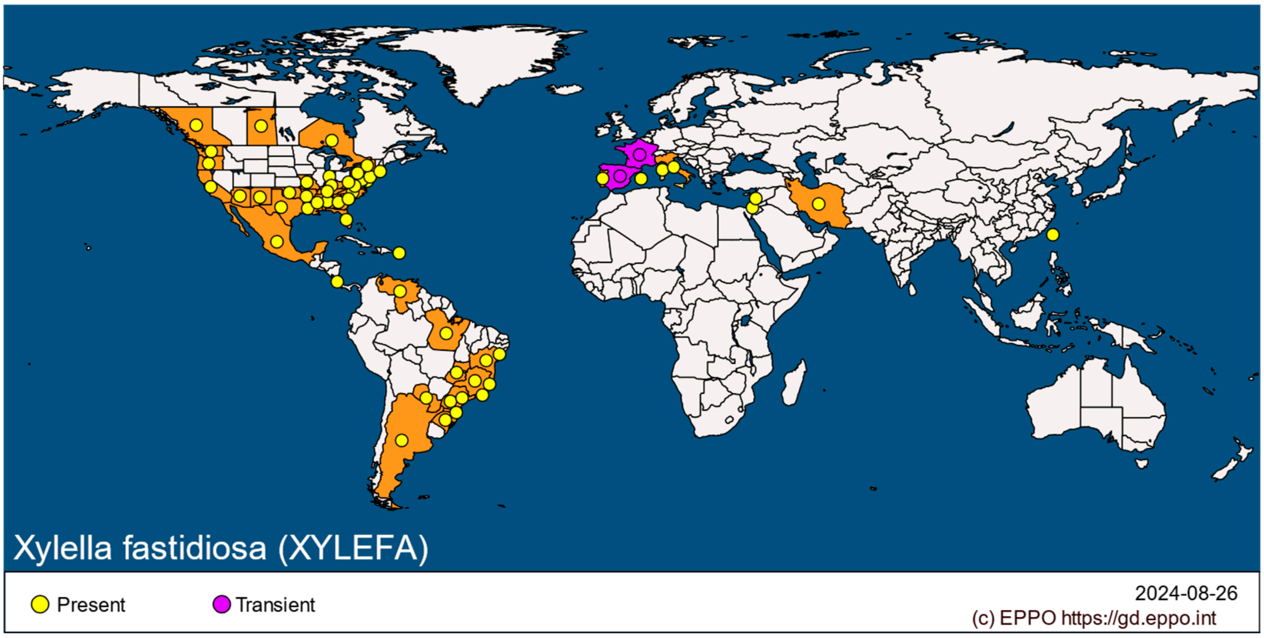

Figure 1. The global distribution of *Xylella fastidiosa* according to the EPPO database.

3. Proposed Methodology (Or Materials and Methods)

The concept underlying the low-cost system design and development is grounded in the correlation between electrical resistance (ER) and hydration levels within tree stem tissues (stem water) [14], which also has an inverse relationship with electrical conductivity (EC) [15].

$$\sigma = \frac{1}{\rho}$$

3.1. System Description

The aforementioned low-cost system utilised various electronic materials in order to measure and compare the stem water percentage in two distinct branches of an olive tree. During design and development of the system, these exact components are used: (1) Raspberry Pi Model 3 B+ with Raspberry Pi OS installed, (2) INA3221 board, (3) Real Time Clock board, (4) DC-DC Buck Converter Step Down LM2596, (5) Relay, (6) USB modem, (7) Battery pack, (8) Solar panel.

The system was programmed to record one measurement every half hour. After this procedure, the data are saved in a .csv file locally on the microcomputer, with timestamps to indicate the precise time of each reading. Finally, the system transmitted the data files compressed in a .zip file format to the Ionian University's CMOD Lab server for backup storage on a daily schedule via GSM internet connection.

For the measurements, percentage was used as an indicator of stem water content. The percentage range corresponds to a range of EC and is inversely proportional to the ER. The measurement is calibrated such that 100% represents the pins being submerged in water, while 0% corresponds to the pins being exposed to air or connected to an insulator. The various electronic components of the proposed low-cost system are presented in Figure 2.

3.2. Field Testing

For the in situ investigation, a large olive tree in a widely cultivated orchard situated near the town of Ostuni, Italy, was selected. In this location, multiple olive trees had previously been uprooted by agronomists due to recent *X. fastidiosa* infestations. The cultivator and landowner of this orchard informed the researchers that this specific tree was also diagnosed with *X. fastidiosa*. As expected, the tree utilised for the experimentation was also uprooted by the agronomists in March of 2024.

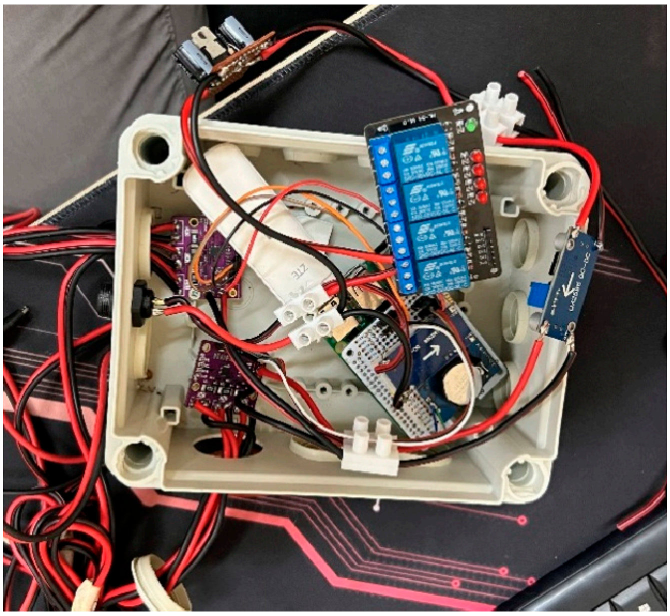

Figure 2. The low-cost system utilised in the laboratory setting during the assembly of the various electronic components.

To install the system, two small holes, as shown in Figure 3, were drilled per sensor at different branches to enable a comparative assessment of the variability in stem water content across the branches.

Figure 3. The electrical conductivity probes were installed on-site in the tree.

4. Results

The comparative analysis of stem water content in two olive tree branches spanned from July to November 2023, as depicted in Figure 4. This figure illustrates the percentage changes in stem water content over time for both Branch 1 (B1), represented in red, and Branch 2 (B2), represented in blue, with the data smoothed using a moving average to enhance the visualisation of the trends.

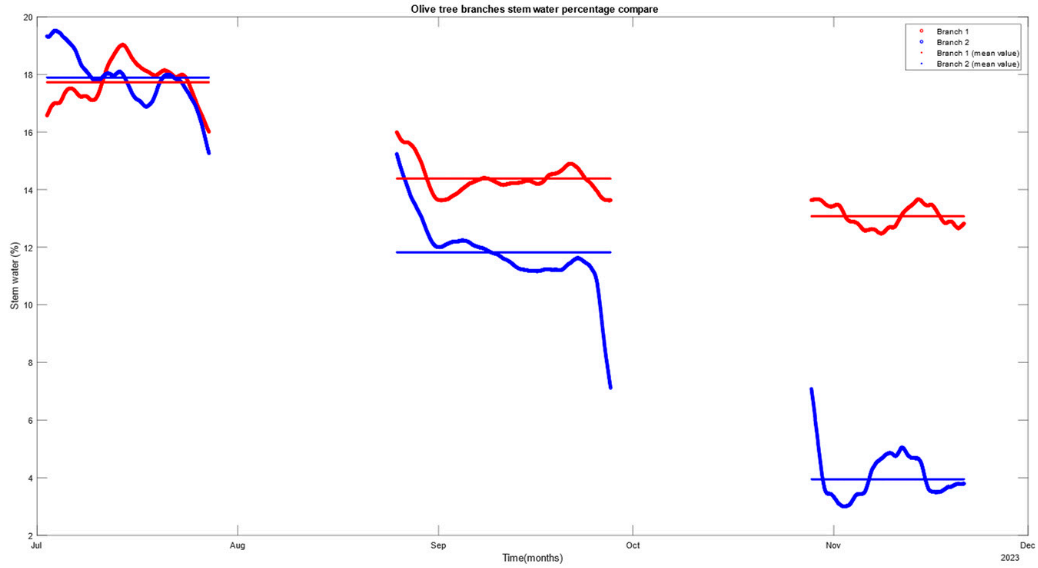

Figure 4. A comparative analysis using MATLAB R2023a version 9.14 (The MathWorks, Inc. (2023). MATLAB R2023a. Natick, MA, USA) of stem water content levels as a percentage across olive tree branches during the July to November 2023 period.

In July, the two branches exhibited relatively similar stem water content levels, with B1 having an average water content of 17.7% and B2 recording slightly higher levels at 17.8%, resulting in a 0.17% difference.

During the latter part of August and throughout September, a noticeable divergence emerged. B1's stem water content steadily decreased, reaching an average of 14.3% by the end of September. Furthermore, B2 exhibited a more significant decline, with levels reaching 11.8%, resulting in a 2.5% difference between the two branches.

This trend continued through November. By the end of the study in November, B1 showed a small decrease in stem water content, which was 13%, with only a 1.1% decline from September levels. In contrast, the average stem water content of B2, calculated as the most significant decrease with a percentage of 3.9%, reflected a 7.9% drop from its September levels and a 9.1% variation compared to B1.

5. Discussion

The observed variation in stem water content between the two olive tree branches throughout the study period may be attributed to a range of environmental and physiological factors. While both branches started with similar water content levels in July, the consistent decline in B1 and the more pronounced decline in B2 suggest differential stress responses, potentially due to microclimatic differences, branch orientation, or early indications of disease.

The 2% difference between the branches in September is noteworthy, as it could signify the onset of physiological stress in B2. Such variations in water content may serve as early indicators of compromised water transport within the tree, a characteristic effect observed in olive trees infected by pathogens like *X. fastidiosa*. Previous research has demonstrated that *X. fastidiosa* infection leads to reduced water uptake and transport, resulting in a noticeable decline in stem water content over time.

Furthermore, the dramatic 9% decrease in stem water content in B2 in November suggests a progression of this potential stress or disease. While this sharp drop could result from environmental factors, such as drought stress or differences in soil moisture availability, it aligns with the known symptoms of *X. fastidiosa* infection, which typically manifests as significant water transport dysfunction.

6. Conclusions and Future Work

This study demonstrates the successful development and field deployment of a low-cost EC probe system for the early detection of *X. fastidiosa* in olive trees. By continuously monitoring stem water content, this system offers a practical, real-time, and sustainable solution that empowers cultivators to identify the presence of the pathogen before visual symptoms, such as Olive Quick Decline Syndrome, become apparent. The results from the field trial, conducted on an olive tree in Southern Italy, indicate that changes in water conductivity can be reliably associated with the progression of *X. fastidiosa* infections.

Compared to traditional laboratory-based diagnostic methods like PCR, this system provides an affordable and scalable alternative, particularly for regions where resources for constant monitoring may be limited. The integration of solar power and GSM data transmission further enhances the system's utility, enabling continuous monitoring even in remote areas. The system's ability to transmit data to a central server facilitates large-scale monitoring across multiple locations, supporting a coordinated and proactive approach to managing the spread of *X. fastidiosa*.

Future research will aim to improve the sensitivity of the system and extend its application to a wider range of environments and tree species or even to more diverse applications such as fire spread simulation. Expanding field trials and refining the probe design can lead to broader adoption of this technology, ultimately contributing to the safeguarding of olive cultivation, which is vital both economically and culturally in affected regions. Through early detection and intervention, this system could play a crucial role in mitigating the devastating effects of *X. fastidiosa* on the olive industry.

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Abbreviations

The following abbreviations are used in this manuscript:

EC	Electrical Conductivity
GSM	Global System for Mobile Communications
ODQS	Olive Quick Decline Syndrome
UAV	Unmanned Aerial Vehicle
GIS	Geographic Information System
ER	Electrical Resistance

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