An Internet Platform to Monitor Plant Pathogens Spread: The Italian Case of Xylella

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Abstract —The numerous species of harmful organisms of tropical origin represent real phytosanitary emergencies that are bringing sectors of agri-food production to their knees, determining negative economic consequences for many farms and significant repercussions on the management of the territories on which production activities insist. For some years, a phytosanitary emergency affects tree species of the Mediterranean scrub, especially the olive trees in the south of Italy: Xylella Fastidiosa (Xf) infection. In this scenario, the paper aims to describe a proposed internet platform, developed in order to support farmers in pathogen monitoring, providing information about the crop and the cropping environment. It is able to provide information about Plant Sap Flow Density, Normalized Difference Vegetation Index and Vapor Pressure Deficit. Information was represented using interactive maps able to tell the overtime parameters trend. Stakeholder, can access to the olive oil trees maps, obtaining in a single view the risk derived from the Xf contagion. The platform could benefit farmers and other stakeholders interested in analysis and territorial sustainability (decision makers, researchers, citizens and biologists).

Index Terms—Environmental monitoring platform, Pathogen monitoring, Decision support system, Smart farming, Xylella Fastidiosa, Olive oil

I. Introduction

The invasive species of agricultural interest cause every year, at world level, economic damage about ten times higher than those due to natural disasters [1]. This number is expected to increase due to global warming. The numerous species of harmful organisms of tropical origin, that have recently settled in the Mediterranean basin, represent real phytosanitary emergencies that are bringing sectors of agri-food production to their knees, determining very negative economic consequences for many farms and significant repercussions on the management of the territories on which production activities insist. Prevention and "early detection" actions, together with the design of sustainable control systems, represent the key actions to be developed to prevent an invasive process from resulting in a phytosanitary emergency [2].

For some years, unfortunately, a phytosanitary emergency affects tree species of the Mediterranean scrub, especially the olive trees in the south of Italy: Xylella Fastidiosa (Xf) infection [3]. The disease on the olive tree begins to manifest itself with some marginal or apical necrosis of the leaves, which widen affecting the entire leaf plate, and with localized desiccation of branches and small branches. The leaves do not fall until the rainy season (late autumn) and the affected branches, initially few and isolated, dry up and are clearly visible on the diseased olive trees and tend to increase in number and size, up to affecting large portions of the foliage. From season to season the development of the entire plant slows down, the buds and branches develop with little vigor and, finally, the olive trees wither rapidly and die [4]. The olive disease observed in the south of Apulia region, has been called “Complesso del Disseccamento Rapido dell’Olivo”, for which the acronym CoDiRO was coined.

Enormous efforts are made in the context of funded European projects (i.e. https: //www.ponteproject. Eu /; https://www.xfactorsproject.eu/), scientific research to date has working to find practical solutions to counter the spread and symptoms of these infections. With a view to prevention, research and approaches with a high level of knowledge must be implemented in olive growing areas where the bacterium is not yet present through constant monitoring of both the bacterium itself and its vectors.

In this context born the Antidote research project (www.antidote-project.it), a system for the diagnosis and monitoring of Xf which, based on interdisciplinary skills, makes it possible to identify the status of some plant parameters (xylem) and the geographical conditions (climatic-environmental, territorial-managerial) which, individually or combined, can characterize, trigger, promote or accelerate infections due to Xf and subsequent symptoms of desiccation. The final goal of the system is to map and anticipate the risk of desiccation in one or more plants present in a monitored field.

Particularly, the paper aims to describe one of Antidote project’ solutions, an internet platform developed in order to support the farmer in pathogen monitoring, providing information about the crop and the cropping environment. This information could be useful to take the right decisions in farming. Although the platform was primarily intended for the farmer, several players can benefit from its use such as decision makers, researchers, citizens and biologists.

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II. Materials and Method

Among the components developed in Antidote project, there is an internet platform capable to collect and analyze the data coming from the sensors placed in a field of olive trees and provide information about the possible presence of the pathogen in the trees and the territorial spread of the bacterium. In order to develop the Antidote internet platform a methodology composed by three steps was defined:

Step 1: Defining the platform requirements. A Software Requirements Specification (SRS) document, an official statement of what the system developers should implement, was generated. It includes both the *user requirements* for a system and a detailed specification of the *system requirements*. User requirements are statements about which services the system is expected to provide the users and the constraints under which it must operate, while system requirements are more detailed descriptions of the software system's functions, services, and operational constraints [5].

Step 2: Designing the platform architecture. This step aims to design the system structure composed by the several software components, the related externally visible properties and the relationships among them [6]. Among the common architectural patterns, the three-tier architecture and Model-View-Controller (MVC) pattern were adopted.

Step 3: Implementing, testing and validating the platform. The implementation of the platform plays a crucial role in software engineering. In fact, during this step, it is necessary to deal with some common issues, such as the reuse of code and configuration management. Testing the system is the key to show that a program does what it is intended to do and to discover defects in the program. The validation phase was conducted using focus group methodology. A focus group is a group of experts whom the researchers involve in the discussion of research issues. The focus group allows to discover insights that would be less accessible without the interaction found in a group [7]. Five focus groups were established, each one composed by 5 experts. Each focus group was characterized by a specific role of the user potentially interested in X*f* and aimed to investigate about the benefit that this role can obtain from the platform.

III. A Proposed Pla Tform for Xylella Monitoring and Forecasting

ANTIDOTE project has developed a system for diagnosing and monitoring X*f* which, based on interdisciplinary skills, identifies the status of the plant xilema and the climatic-environmental and territorial-management conditions that, isolated or combined, can characterize, trigger, promote, or accelerate infections due to X*f* and subsequent symptoms of dehydration. Combining the level of danger (severity of invasion of Xf), exposure (verified or suspected, infected plants) and the vulnerability (plant predisposition to be infected) the system aggregates information useful to the definition of appropriate prevention or healing techniques.

A. Platform Requirement

The system's main user requirements consist in collecting environmental data, relevant to the Xf monitoring of a field of olive trees, and providing related interactive visualization, analysis and reporting tools.

The environmental data monitored within the Antidote project are based on health parameters of the olive trees: the Plant Sap Flow Density [8], the Normalized Difference Vegetation Index (NDVI) and the Vapor Pressure Deficit (VPD). The users need to carry out spatial and time-related data exploration through i) interactive maps showing the spatial distribution of each health parameter; ii) box and whiskers plots showing the upper, lower, average and outlier values and the interquartile ranges (IQRs) of each parameter; iii) time series showing the time course of the parameters. Given a subset of data, the users need to export it to a PDF report and to an interoperable file format to carry out further analysis with third-party software. To meet users' requirements, the internet platform needs to address the software integration with the ANTIDOTE's environmental sensor system, querying the underlying data warehouse on each user's request on a spatial and time basis.

B. Platform Design and Architecture

The internet platform adopts the abovementioned MVC three-tier architecture represented by Fig. 1. This structure conceives the platform as composed by three different tiers. The *Presentation Tier* that is the graphic interface through which the user interacts with the system. Thanks to this layer the user access and explore the environmental data*; the Business Tier* able to manage, process and share the data versus the previous tiers; *the Data Access Tier* capable to store/retrieve the georeferenced environmental and user data, using a *PostgreSQL* database. The MVC development paradigm, focusing on presentation and business layers, aims to increase the flexibility and reuse of the code [9]. Particularly, the Model component manages the system data and the related operations; the View component defines and manages how data is presented to the user. At last, the Controller component manages user interaction and passes these interactions to the View and the Model components [3]. When the user interacts with the system, the latter queries the *RESTfulAPI* service of the data analysis platform to retrieve spatially and temporally aggregated data from the environmental sensors, and eventually display them on WebGIS-style interactive maps.

C. Platform Implementation and Testing

The core functionality of the Antidote platform consists in providing interactive thematic maps. A thematic map is a map designed to demonstrate particular features or concepts related to a specific theme or subject area [10]. Interaction features add advantage to thematic maps, because values can be turned on or off by the map reader [11].

The implemented system provides interactive thematic maps showing the environmental data recorded by the sensors attached to the trees affected by X*f*.

For each tree's health parameter, the system provides data up to the day before (from 12 am to 11:59 pm). Users can query different time windows and temporal aggregations. The background for the thematic maps is an orthophoto – an aerial photograph and high precision satellite image – of the field of olive trees, allowing users to easily identify the referred trees. Thanks to this solution, the following three interactive maps allow users to inspect the health parameters recorded by each sensor installed on the crop, on a spatial and time basis (daily, weekly, monthly).

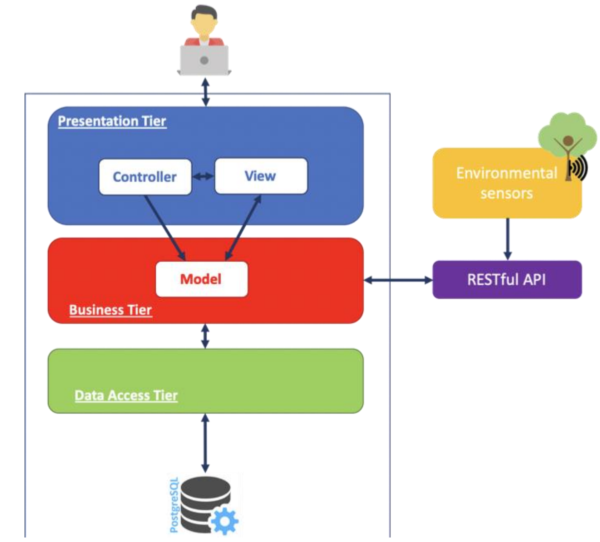

Fig. 1. Architecture of the ANTIDOTE platform.

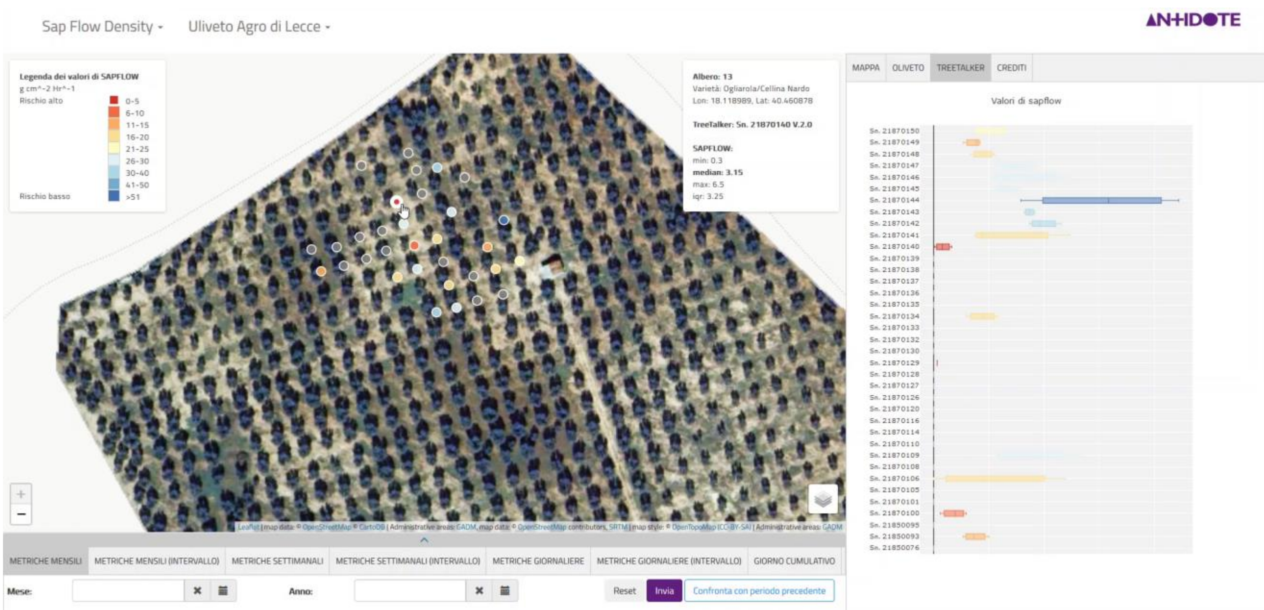

Fig. 2. Antidote platform providing plant sap flow density map and box plot

Map 1: Plant Sap Flow Density

The Sap Flow Density map (Fig. 2) shows the xylem flow density values recorded by each sensor installed on the trees. The xylem flow is responsible for transporting water and nutrients from the soil to the leaves and active cells of the plant. The monitoring of this flow provides information on the lymphatic system's health and its response to environmental stress due to the variation of the water potential between soil and atmosphere. The persistence of low values indicates a plant suffering from soil water shortage and/or desiccation of its parts.

Sap Flow Density values are typically between 0 (no flow) -2 -1 and 80 gcm hr, nonetheless, can vary between different plants. Sap flow is strongly affected by the vapor pressure deficit of the atmosphere, which in turn depends on air temperature and relative humidity of the air.

Map 2: Normalized Difference Vegetation Index (NDVI)

The Normalized Difference Vegetation Index (NDVI) map (Fig. 3) helps to understand the general health of the leaves. In fact, the NDVI index is useful for monitoring drought stress or desiccation of plants as, in the event of water stress or desiccation, the leaves change color (from green to yellow-brown) and lose turgor, thus decreasing the value of the measured index. The index values are theoretically between -1 and +1. However, negative values are not representative of vegetation. Values below 0.3 may indicate that the plant is heavily stressed. Values above 0.6 are typical of plants that are in good health.

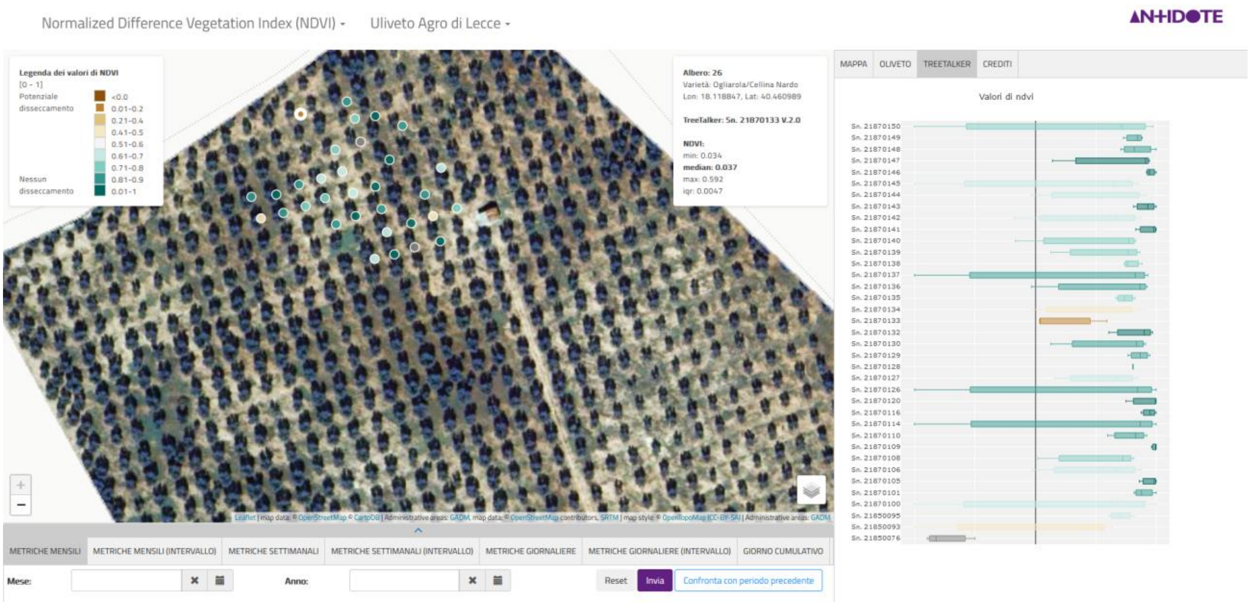

Fig. 3. ANTIDOTE platform providing normalized difference vegetation Index (NDVI) map and box plot

Map 3: Vapour Pressure Deficit (VPD)

The Vapour Pressure Deficit (VPD) map (Fig. 4) shows the values of the vapor pressure deficit. This map helps to understand the force that drives the movement of water vapor from the inside of the leaf to the outside. In fact, the loss of water through transpiration will be the greater the higher the VPD. Intermediate VPD values allow the plant to activate the xylem flow, transporting water and nutrients from the roots to the leaves. Excessively low or high VPD values result on plants' severe physiological stress, such as excessive consumption and rapid depletion of water from the soil. VPD values typically vary between 0 kPa (air saturated with water vapor) and 3 kPa (dry and hot air).

Fig. 4. ANTIDOTE platform providing Vapour Pressure Deficit (VPD) Map and box plot

The system entails mechanisms for cross-referencing between multiple plots, thus for each map is possible to visualize the time course of the related parameter as a time series.

The temporal comparison helps users visualizing the long- term seasonal/annual trends and searching for anomalies due to the deviation from the seasonal average of the monitored periods.

For instance, the user can query the system to obtain the Plant Sap Flow Density values in a selected time window aggregated on a daily, weekly or monthly basis. Fig. 5 shows the internet platform displaying the Plant Sap Flow Density average value for each month of the last two years.

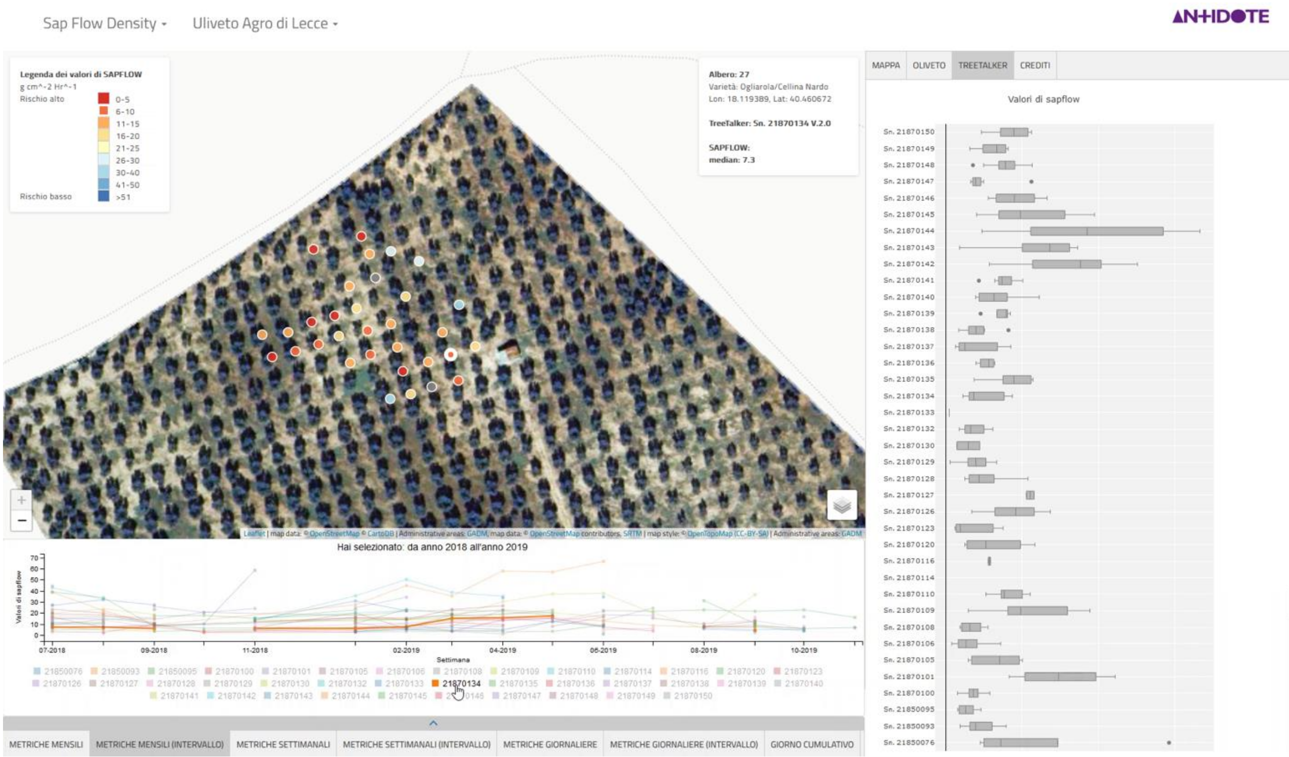

Fig. 5. ANTIDOTE platform providing time series for Plant Sap Flow Density values

The entire system was tested in a real case study. An olive tree field placed in the south of Apulia (Italy) was chosen and the sensors were placed to monitor the plant and the related cropping environment. This data feed the Antidote platform that was tested involving 5 users for each target of stakeholder (farmers, policy makers, researchers, biologists, citizens) for a total of 25 users. Feedback, suggestions and ideas for improvement were collected using the focus group methodology.

IV. Conclution and Follow Up

According to the defined methodology, a platform for Xf monitoring was established. This platform, is able to collect, process and visualize data coming from a set of sensors installed in olive trees field. After the processing phase, Antidote platform is able to provide information about Plant Sap Flow Density, NDVI and VPD. This information was represented using interactive maps able to tell the trend of the parameters over time. Thanks to the Antidote platform it was possible to realize a "personalized" monitoring and forecasting systems for Xf. Stakeholder can access, near real- time, to the dehydration level map of the areas covered by the monitoring, obtaining in a single view the risk derived from the combination of 3 specific information: danger, exposure and vulnerability. The methodological and technological-informatics structure, made available to consumers, both private and local authorities and decision- makers, provides a strong impetus to the innovation of diagnostic, care and prevention interventions and related planning directions.

Antidote platform was designed as versatile, modular and scalable, in order to transfer easily the developed solution to solve similar problem in different contexts and/or similar issues in the same context. For example, the platform could be implied to monitor other pathogens that affect Olive trees (e.g. olive fly) or other kind of plants (e.g. the pathogenic fungi of the wine). According a view of horizontal transferability of the solution, Antidote platform could be used in all case where environmental monitoring is useful such as the monitoring of the environmental conditions of the works exhibited in museums. Moreover, the proposed platform is not tied to a specific sensing technology. So, with little configuration activity, it will be able to work starting from the data collected by any type of sensor.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Angelo Corallo: Supervision, Funding acquisition. Francesco Filieri: Visualization, Writing-original draft. Maria Elena Latino: Conceptualization, Data curation, Investigation, Methodology, Supervision, Validation, Visualization, Writing-original draft, Writing-review & editing.

Marta Menegoli: Investigation, Visualization, Writing-original draft.

Marco Lucio Sarcinella: Visualization, Writing-original draft.

All authors approved the final version.

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