TLS Radiometric Analysis for Monitoring Plant Diseases in Apulia's Olive Groves

Noemi Pagano(✉), Eufemia Tarantino, and Alberico Sonnessa

Department of Civil, Environmental, Land, Construction and Chemistry (DICATECh), Politecnico di Bari, Via Orabona 4, 70125 Bari, Italy
n.pagano@phd.poliba.it, {eufemia.tarantino, alberico.sonnessa}@poliba.it

Abstract. Threats to agricultural environments are constantly rising due to global trade, dangerous infections, harmful pathogens, anthropogenic pressure, and climate change. Simultaneously, the world's population is increasing at a rate of approximately 70 million people per year, driving the demand for food and emphasizing the need for effective crop health monitoring strategies.

In Southern Italy, the Apulia region is famous for its centuries-old olive groves, recognized by UNESCO for their cultural and landscape significance. However, this vital resource is seriously threatened by the *Xylella fastidiosa* (Xf) bacterium, which was first identified in Apulia in 2013. Over the past decade, the infection has spread rapidly in Salento, causing irreversible damage and gradually extending throughout the region.

To control this pathogen, the Apulia region has created a geodatabase of areas affected by Xf (i.e., infected, containment, and buffer zones), which is available through web mapping services. Various techniques, including non-invasive geomatics and remote sensing methods, have been employed to monitor the progression of the disease. This study presents preliminary results from the analysis of high-resolution three-dimensional point clouds acquired in the Gorgognolo area using a terrestrial Light Detection and Ranging (LiDAR) sensor.

To identify the impact of Xf on olive trees and to monitor the development of the infection, the work focuses on radiometric metrics, i.e. intensity. The results demonstrate how remote sensing technologies can be used to track plant diseases and assess the progression of infection.

Keywords: *Xylella fastidiosa* · LiDAR · Apulia Region · LiDAR intensity · plant disease monitoring

1 Introduction

The agricultural environment has deteriorated rapidly in recent decades due to multiple factors, including increasing anthropogenic pressure, pollution, the reckless use of agricultural land and water resources, the expansion of global trade and the evident and catastrophic effects of climate change. The world population is growing at a rate of 70

© The Author(s), under exclusive license to Springer Nature Switzerland AG 2026
O. Gervasi et al. (Eds.): ICCSA 2025 Workshops, LNCS 15891, pp. 256–267, 2026.
https://doi.org/10.1007/978-3-031-97617-9_17

million per year [1], thus exacerbating the demand for food supply and posing new challenges for sustainable agricultural production and global food security [2]. Agricultural ecosystems in the Mediterranean area are also threatened and the protection of biodiversity, which is essential to ensure the stability of local ecosystems and agricultural production, has become a recognized priority and endorsed by the United Nations in Agenda 2030 in different Sustainable Development Goals(https://unric.org/it/agenda-2030/).

In Italy, the Apulia region, located in the south of the peninsula, is an emblematic example of this challenge. Well-known for its centuries-old olive groves, which constitute not only an economic resource but also a distinctive element of its cultural heritage and landscape [3, 4], Apulia has suffered the effects of climate change [5, 6], alongside the effects related to the spread of the bacterium *Xylella fastidiosa* (Xf). First identified in 2013 in the Salento district, Xf has rapidly proliferated, causing a significant drop in agricultural productivity, with tremendous economic impacts at a local and national scale. Infected areas cover more than 200.000 hectares, amounting to around 21 million trees and the associated huge financial losses.

The impact of this plant disease has irreversibly transformed the Apulian landscape, leading to the loss of productive olive trees and forcing farmers to shift cultivation practices, reducing agricultural biodiversity. However, countering the Xf pathogen has set new challenges, focused on increasing resilience to these potentially catastrophic events.

As a result, the crisis caused by *Xylella* is no longer an isolated issue in the phytosanitary sphere, but affects the entire economic, social and environmental context. On this side, the public awareness of Xf and effective communication on the related risk can help the public in fully understanding the problem, and lead policymakers in their management and prevention plans, as demonstrated in different research fields [7–9]. *Xylella*, initially confined to the olive groves of Salento, has now expanded to new crops, including almonds, cherries and vines, through its aggressive variants, thus raising the economic implications of its spread. For instance, almond production in Apulia covers about a third of the national requirement and is particularly vulnerable to infection. To cope with its spread, local and regional authorities have adopted a series of containment measures, set out in multiple decrees [10], which include the felling of infected plants and the continuous monitoring of hazardous areas. Since a way to permanently eradicate such epidemics is still under study, despite numerous scientific efforts and encouraging discoveries [11]. Monitoring is the only action that can be carried out to better understand this phenomenon. To fulfill these obligations and provide up-to-date and official information, the Apulia Region has set up a constantly updated database containing the perimeter of infected, containment and buffer zones, available via web platform at (https://webapps.sit.puglia.it/freewebapps/DatiFasceXF/index.html), in a user-friendly layout.

In the domain of environmental monitoring, and particularly for precision agriculture, geomatics is the discipline that assumes a cornerstone role [12]. Light Detection and Ranging (LiDAR) is one of the most promising non-invasive geomatic technologies [13–15]. When used with terrestrial devices like Terrestrial Laser Scanners (TLS), it

constitutes an essential tool for obtaining precise dimensional information in both agricultural and forestry contexts [16]. Recent studies have demonstrated the potential of intensity-based segmentation techniques for vegetation analysis and classification [17]. These approaches exploit the radiometric response of LiDAR to improve the detection of physiological changes, providing a valuable complement to traditional and consolidated spectral data. This paper reports the results of an in-depth analysis of high-resolution three-dimensional point clouds, acquired by a TLS, on a set of olive trees located in the area of Gorgognolo (BR). The analysis focused on the understanding of the intensity parameter of the laser returns to distinguish the specific characteristics of the two main components of the tree: the trunk and the leaf canopy. Afterward, a detailed investigation of the progression of the *Xylella fastidiosa* infection, which seriously challenges the survival of the olive groves, has been carried out.

2 The Case Study

The Gorgognolo area, an agricultural territory near the town of Ostuni (BR), belongs to the Salento peninsula and is in the infected zone.

The investigated location, covering an area of approximately 8250 m^2, was surveyed for the first time in August 2023, referred to as T_0. Two additional measurements have been carried out in January 2024 (T_1) and May 2024 (T_2).

The Apulia Region's Phytosanitary Observatory has revised the extension of affected areas, now including Triggiano and Santeramo in Colle, and detected a new outbreak of the multiplex and pauca subspecies, recently identified respectively, near the southern township of Santeramo and Bari. Following an extensive monitoring activity, the Observatory published four official determinations (n. 91, 92, 93 and 94) [18], which provides an update of the classification of the areas bounded by subspecies and displays revised maps illustrating the location of the sampled plants and the corresponding laboratory results. In addition, through the decree of the Director of the Phytosanitary Observatory Section dated 23 August 2024, additional phytosanitary measures have been addressed and new subspecies (i.e. fastidiosa, multiplex and pauca) have been identified. The informations are regularly uploaded on the official website of the Apulia Region (www.emergenzaxylella.it). In order to address the increasingly critical situation, despite considerable efforts over the past decade, Resolution No. 1593 – 25 November 2024 [19] was issued, introducing an updated classification of infected areas. To give a visual idea of the progress of the pathogen, maps (Fig. 1) illustrating the situation in April 2024 and its latest update in November 2024 are shown.

3 Methodology Employed

In forestry, TLS technology is increasingly used to evaluate the geometric properties of plants [20]. By shooting laser pulses that rebound off neighbouring objects, the TLS measures the distance by timing the beam's return to the instrument. Along with the spatial coordinates, the collected data, which are visualized as point clouds, contain information on the intensity of the reflected signal [21, 22], which can be used to investigate the physical characteristics of the surface deep [23]. It should be noted that the

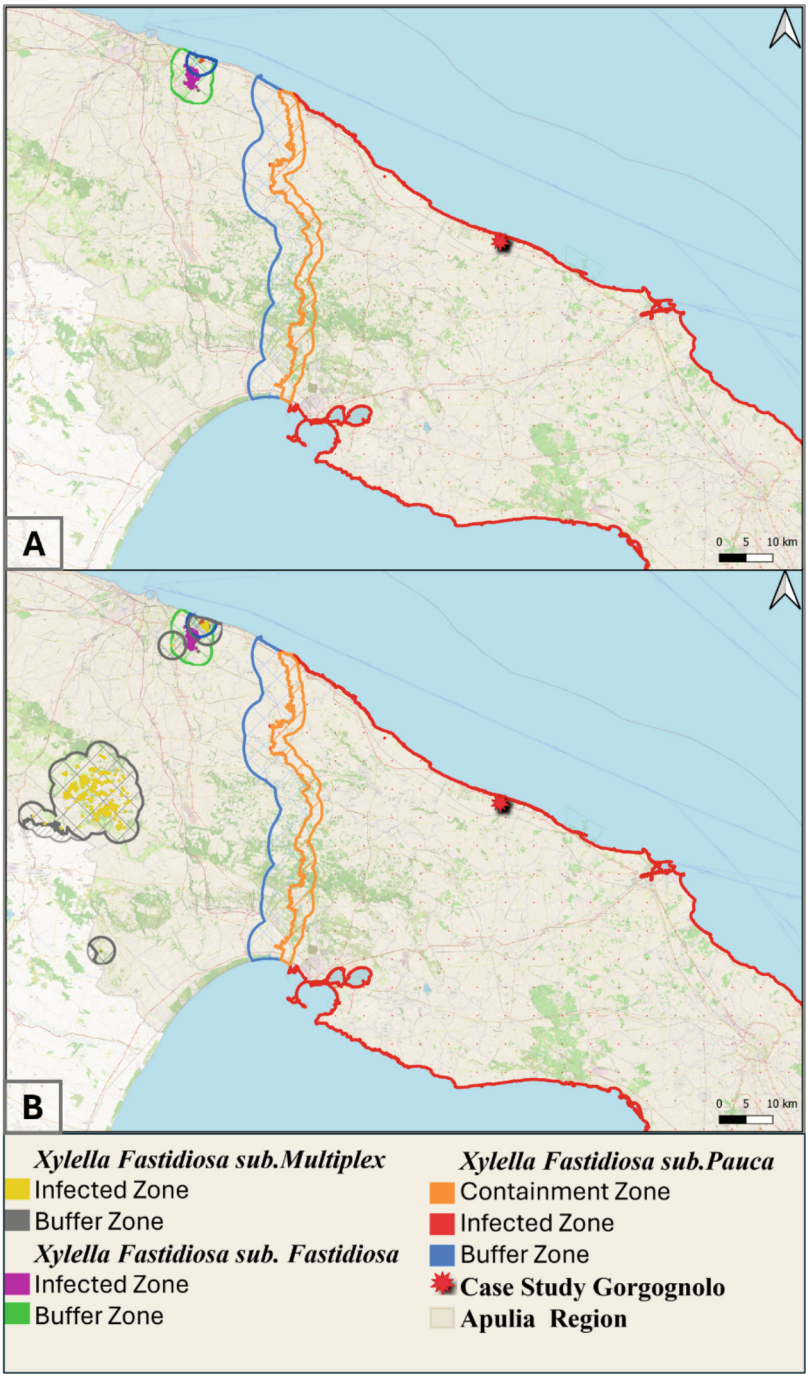


Fig. 1. Boundaries of the areas affected by *Xylella fastidiosa* (Apulia Region web map service) in April 2024 (A) and November 2024 (B). The study area is marked with a red star.

TLS provides data on a 16-bit scale, so the intensity values can vary from a minimum of 0 to a maximum of 65535.

A Trimble TX8 (Fig. 2), an advanced laser scanner with a maximum range of 300 m and an acquisition rate of one million points per second, and a laser wavelength of 1.5μm, was used to collect the data [24]. Because of the wavelengths available, the laser is less affected by aerosols and humidity than shorter wavelengths, ensuring more stable measurements in changing conditions [25]. The instrument produces precise, high-density point clouds, which can be enriched with colour (RGB) information thanks to the integrated 10 megapixel full-field camera.

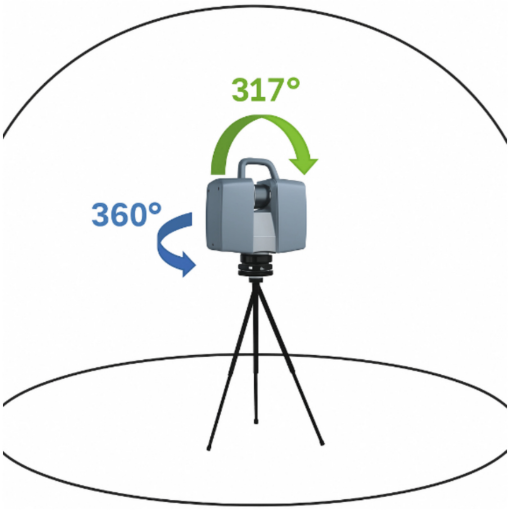


Fig. 2. The TLS used in Gorgognolo is characterized by a 34 mm beam diameter at 100 m, a 317° vertical field of view (FOV), limited below the laser scanner, and a horizontal 360° FOV, 80 μrad angular accuracy.

Determining the intensity of the data is a key component of this analysis, as this information may prove useful in identifying specific alterations in infected plants. Their interpretation, however, requires careful handling of variables that may affect signal intensity, such as triangulation, sitting, laser angle of incidence, and atmospheric conditions. Notwithstanding the difficulties linked to the lack of universal standardization for the normalization of these data, this paper explores a possible approach to using the intensity parameter as a diagnostic tool in assessing olive tree health.

The accuracy of the instrument in standard mode ranges from ±2.8 mm with a confidence level of 68.3% to ±8.5 mm with a confidence level of 99.7%.

4 Data Acquisition and Processing

The present work is framed in a monitoring campaign started in August 2023 and constitute a refinement of the analyses carried out previously and presented in [26]. In keeping with the expectations of reliable monitoring, scan positions, recorded by a geodetic

GNSS receiver, and operating modes have been set out in the first measurement and maintained through the whole period (Fig. 3). The complete single scan of the study area of approximately 8,250 m^2 took approximately five hours to complete, including positioning of the TLS stations, data acquisition and field control.



Fig. 3. Data acquisition in August 2023, January 2024, and May 2024, (T_0, T_1 and T_2).

The preliminary point cloud co-registration has been performed via Trimble Real-Works software (Trimble Navigation Limited, USA). The pairwise scan recording reached an average accuracy of 12mm, by using targets mounted on tripods as a reference (Fig. 4).

The point clouds were then processed using CloudCompare (https://www.cloudcompare.org/) to remove noise and outliers, such as spikes or anomalous reflections. One of the filters used in the field was the SOR (Statistical Outlier Removal) algorithm, applied with default parameter settings to ensure the consistency and reliability of the dataset.

The analysis was performed targeting four olive trees, exemplary of the conditions in the study area, as they are characterized by different degrees of desiccation. The targeted trees are named as F,23,24,25 (Fig. 5).

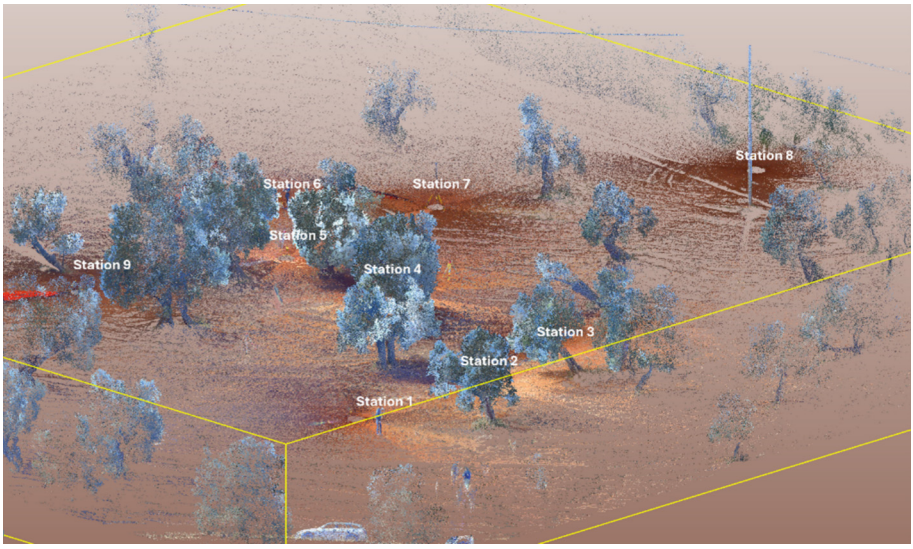


Fig. 4. Raw point cloud acquired in the survey of May 2024, as displayed in Trimble Real Works.

5 Intensity Parameter Analysis

The opportunity of using the intensity radiometric parameter collected during TLS surveys to discriminate between different surface types has been investigated. By understanding and processing the data, it is possible to separate a tree into its main constitutive elements, namely leaves and trunk. However, the susceptibility of the intensity parameter to numerous factors such as environmental conditions (temperature, humidity and pressure), acquisition geometry (distance to the surveyed object, angle of incidence) and scanning mode can considerably affect the analysis [26]. The meteorological conditions during the three surveys ranged from a very summery climate, with peaks of 40 °C during the T_0 measurement to 10 °C in T_1, while the T_2 survey has been carried out in May 2024 in intermediate conditions with a temperature of about 25 °C. To account for this variability, the area containing the objects of interest was extracted, and the related intensity values were normalized on a scale from 0 to 10.

A cloud-to-cloud estimation was also carried out to evaluate changes in the geometry of the trees. Detected differences resulted in values comparable with the instrument sensitivity along the canopy surface, thus ensuring that at least the structural degradation of the wood has not occurred.

A sample of 4 trees, representative of the disease and its effects at different stages, was first segmented by building two macro classes containing trunk and leaves. The average intensity values and the associated standard deviation were then calculated for each class in T0 (Table 1). Once identified, these values were used as references in subsequent scans. Assuming that dry leaves behave as wood, the intervals useful to classify points as trunk or leaf were calculated considering an uncertainty equal to 2σ, thus generating a negligible overlapping zone equal to 0.03%, on the normalized intensity scale (the overlap interval is between 5.03 and 5.33).



Fig. 5. Basemap of the study area. Location of target trees is indicated by triangles and numbered (source: Google Earth Pro).

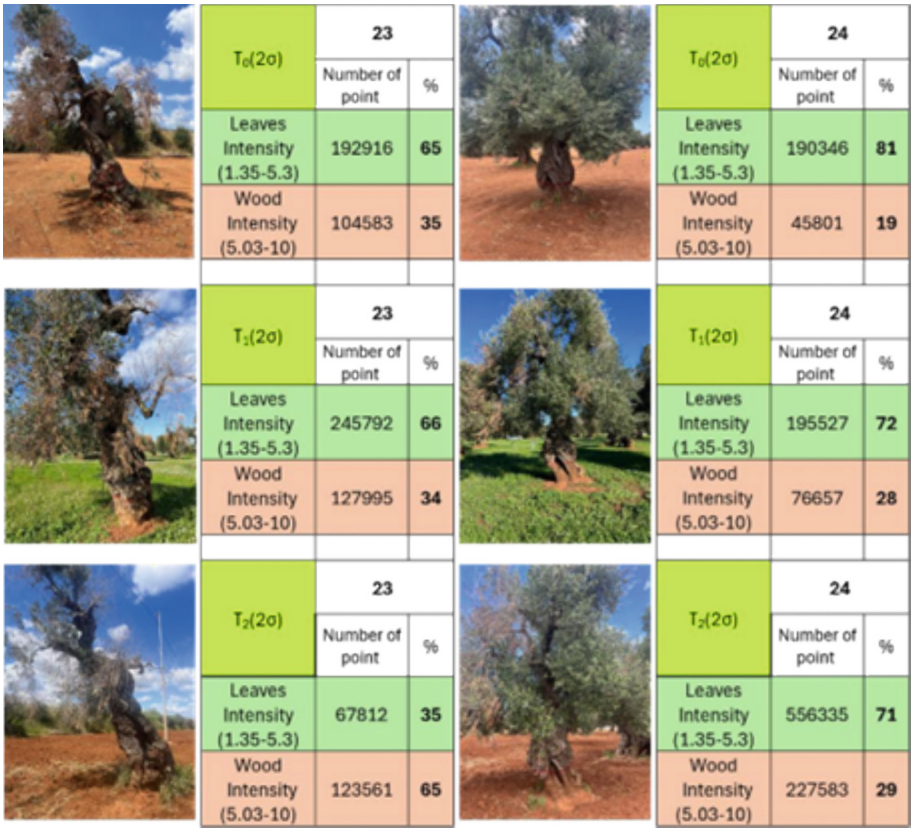
Table 1. Intensity value recorded in T_0

	Trunk (T_0)	Leaf (T_0)
Average Intensity	7.7	3.3
Std. dev.	1.34	0.98

The ranges obtained have been used to characterize the remaining scans, leading to the results shown in the following tables (Figs. 6 and 7).

The pictures are displayed in conjunction with the analyses carried out on the intensity parameter to emphasize how much this parameter closely mirrors the reality recorded during the three monitoring campaigns (T_0, T_1 and T_2).

The results' analysis shows that the tree identified as 23 is the most seriously damaged by the pathogen, with an increasing predominance of the class comparable to wood.



$T_0(2\sigma)$	23	
	Number of point	%
Leaves Intensity (1.35-5.3)	192916	65
Wood Intensity (5.03-10)	104583	35

$T_0(2\sigma)$	24	
	Number of point	%
Leaves Intensity (1.35-5.3)	190346	81
Wood Intensity (5.03-10)	45801	19

$T_1(2\sigma)$	23	
	Number of point	%
Leaves Intensity (1.35-5.3)	245792	66
Wood Intensity (5.03-10)	127995	34

$T_1(2\sigma)$	24	
	Number of point	%
Leaves Intensity (1.35-5.3)	195527	72
Wood Intensity (5.03-10)	76657	28

$T_2(2\sigma)$	23	
	Number of point	%
Leaves Intensity (1.35-5.3)	67812	35
Wood Intensity (5.03-10)	123561	65

$T_2(2\sigma)$	24	
	Number of point	%
Leaves Intensity (1.35-5.3)	556335	71
Wood Intensity (5.03-10)	227583	29

Fig. 6. Classification intensity value collected for every single year for 23 and 24. Pictures and percentage of leaves and wood in T_0, T_1 and T_2, obtained by classifying the point cloud by the intensity value, related to collected for every single year for 23 and 24. The corresponding pictures evidence the evolution of the infection

Over the same monitoring period, tree 25 showed a more uniform trend, with a gradual decrease of the number of points which intensity correspond to leaf between T_0, to T_2 (80%, 75%, 64%) and a simultaneous increase of the points classified as wood, indicating the onset of desiccation.

The least affected tree overall turns prominently out to be 24, as it shows percentages of healthy leaves ranging between 80 and 71%. Although the trend is negative, the tree is still relatively far from the final stage of infection. While tree F initially showed the same trend as tree 24 for T_0 and T_1, it progressed significantly in the last survey and reached a green leaf percentage of 34%.



$T_0(2\sigma)$	25	
	Number of point	%
Leaves Intensity (1.35-5.3)	230681	80
Wood Intensity (5.03-10)	58986	20



$T_0(2\sigma)$	F	
	Number of point	%
Leaves Intensity (1.35-5.3)	176601	80
Wood Intensity (5.03-10)	44477	20



$T_1(2\sigma)$	25	
	Number of point	%
Leaves Intensity (1.35-5.3)	205166	75
Wood Intensity (5.03-10)	69385	25



$T_1(2\sigma)$	F	
	Number of point	%
Leaves Intensity (1.35-5.3)	150355	71
Wood Intensity (5.03-10)	62047	29



$T_2(2\sigma)$	25	
	Number of point	%
Leaves Intensity (1.35-5.3)	531021	64
Wood Intensity (5.03-10)	293337	36



$T_2(2\sigma)$	F	
	Number of point	%
Leaves Intensity (1.35-5.3)	89946	34
Wood Intensity (5.03-10)	177045	66

Fig. 7. Percentage of leaves and wood in T_0, T_1 and T_2, obtained by classifying the point cloud by the intensity value, related to 25 and F. The corresponding pictures evidence the evolution of the infection.

6 Conclusions, Remarks and Further Developments

The potential of adopting laser scanning technology to monitor the damages to olive trees caused by the *Xylella fastidiosa* was confirmed by the results obtained from the analysis of the laser intensity data. This is consistent with preliminary visual and qualitative analysis and confirms that laser intensity is a good proxy for detecting and controlling the progress of the Xf infection on olive trees. The classification between leaf and wood using the radiometric parameter of intensity at different time intervals provided the opportunity to show the progress of drying in the four targets, highlighting which trees are at an early stage of infection and the ones already severely affected by the disease.

However, due to the operator's experience in performing and processing the survey and the time required (approximately 1000 m^2/hour), static TLS is not the most cost-effective option for crops larger than one hectare. This problem could be overcome by using drone-mounted laser sensors, which can cover large areas in a relatively short time and with reduced operating costs. On the other hand, the accuracy of the observations

collected by this technique is lower than an analogous dataset collected using a static TLS, so further testing is needed to verify its effectiveness.

The methodology proposed in the study makes it possible to operate independently of atmospheric and/or solar conditions, unlike other technologies such as NIR (Near Infrared), which, although a more than established solution in the field of monitoring vegetation and its physiological state, do not allow penetration inside the canopy.

Acknowledgments. The authors want to thank Dr. Pietro Sumeraro at ARIF PUGLIA (Agenzia Regionale Attività Irrigue e Forestali) for supporting the logistics.

References

1. Sadigov, R.: Rapid growth of the world population and its socioeconomic results. Sci. World J. **2022** (2022). https://doi.org/10.1155/2022/8110229
2. Food and Agriculture Organization of United Nation: The future of food and agriculture – Alternative pathways to 2050 (2018)
3. Acciani, C., de Gennaro, B.C., Fucilli, V., Roselli, L.: Valutazione dell'impatto economico e paesaggistico causato da *Xylella fastidiosa* sull'olivicoltura del Salento (2015)
4. Ciervo, M.: Il disseccamento degli olivi in Puglia, evidenze, contraddizioni, anomalie, scenari. Società Geografica Italiana (2020)
5. Gioia, A., Bruno, M.F., Totaro, V., Iacobellis, V.: Parametric assessment of trend test power in a changing environment. Sustain. (Switz.) **12** (2020). https://doi.org/10.3390/su12093889
6. Gioia, A., Totaro, V., Bonelli, R., Esposito, A.A.M.G., Balacco, G., Iacobellis, V.: Flood susceptibility evaluation on ephemeral streams of Southern Italy: a case study of Lama Balice. In: Gervasi, O., et al. Computational Science and Its Applications – ICCSA 2018. ICCSA 2018. Lecture Notes in Computer Science, vol. 10964, pp. 334–348. Springer, Cham (2018). https://doi.org/10.1007/978-3-319-95174-4_27
7. Wang, P., Li, Y., Zhang, Y.: An urban system perspective on urban flood resilience using SEM: evidence from Nanjing city, China. Nat. Hazards **109**, 2575–2599 (2021). https://doi.org/10.1007/s11069-021-04933-0
8. Santoro, S., Lovreglio, R., Totaro, V., Camarda, D., Iacobellis, V., Fratino, U.: Community risk perception for flood management: a structural equation modelling approach. Int. J. Disaster Risk Reduction **97**, 104012 (2023). https://doi.org/10.1016/j.ijdrr.2023.104012
9. Schweiger, E.W., Grace, J.B., Cooper, D., Bobowski, B., Britten, M.: Using structural equation modeling to link human activities to wetland ecological integrity. Ecosphere **7** (2016). https://doi.org/10.1002/ecs2.1548
10. DET_494_20_12_2023
11. Latino, M.E., Menegoli, M., Signore, F., Corallo, A., De Devitiis, B., Viscecchia, R.: Micro knowledge as a driver for systemic emergencies management: the case of Xylella in Italy. J. Knowl. Econ. (2024). https://doi.org/10.1007/s13132-024-02210-6
12. Escandón-Panchana, P., Herrera-Franco, G., Jaya-Montalvo, M., Martínez-Cuevas, S.: Geomatic tools used in the management of agricultural activities: a systematic review (2024). https://doi.org/10.1007/s10668-024-04576-8
13. Voegtle, T., Schwab, I., Landes, T.: Influences of different materials on the measurements of a terrestrial laser scanner (TLS). Int. Arch. Photogrammetry Remote Sens. Spat. Inf. Sci. (2008)
14. Baiocchi, V., et al.: First geomatic restitution of the sinkhole known as 'Pozzo del Merro' (Italy), with the integration and comparison of 'classic' and innovative geomatic techniques. Environ. Earth Sci. **77** (2018). https://doi.org/10.1007/s12665-018-7244-6

15. Fascia, R., Barbieri, F., Gaspari, F., Ioli, F., Pinto, L.: From 3D survey to digital reality of a complex architecture: a digital workflow for cultural heritage promotion. In: International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences - ISPRS Archives, pp. 205–212. International Society for Photogrammetry and Remote Sensing (2024). https://doi.org/10.5194/isprs-Archives-XLVIII-2-W4-2024-205-2024
16. Spadavecchia, C., Campos, M.B., Piras, M., Puttonen, E., Shcherbacheva, A.: Wood-leaf unsupervised classification of silver birch trees for biomass assessment using oblique point clouds. In: International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences - ISPRS Archives, pp. 1795–1802. International Society for Photogrammetry and Remote Sensing (2023). https://doi.org/10.5194/isprs-archives-XLVIII-1-W2-2023-1795-2023
17. Miao, Y., Wang, L., Peng, C., Li, H., Zhang, M.: Single plant segmentation and growth parameters measurement of maize seedling stage based on point cloud intensity. Smart Agric. Technol. **9** (2024). https://doi.org/10.1016/j.atech.2024.100665
18. ATTO DIRIGENZIALE, N. 00109 del 23/08/2024 del Registro delle Determinazioni della AOO 1810
19. DEL_1593_2024
20. Spadavecchia, C., Belcore, E., Grasso, N., Piras, M.: A fully automatic forest parameters extraction at single-tree level: a comparison of MLS and TLS applications. In: International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences - ISPRS Archives. pp. 457–463. International Society for Photogrammetry and Remote Sensing (2023). https://doi.org/10.5194/isprs-archives-XLVIII-1-W1-2023-457-2023
21. Tan, K., Zhang, W., Shen, F., Cheng, X.: Investigation of TLS intensity data and distance measurement errors from target specular reflections. Remote Sens. (Basel) **10**, 1077 (2018). https://doi.org/10.3390/rs10071077
22. Kaasalainen, S., Krooks, A., Kukko, A., Kaartinen, H.: Radiometric calibration of terrestrial laser scanners withexternal reference targets. Remote Sens. (Basel) **1**, 144–158 (2009). https://doi.org/10.3390/rs1030144
23. Peppe, P.J., et al.: High-resolution geomatic and geophysical techniques integrated with chemical analyses for the characterization of a Roman wall. J. Cult. Herit. **17**, 141–150 (2016). https://doi.org/10.1016/j.culher.2015.06.005
24. Almukhtar, A., Saeed, Z.O., Abanda, H., Tah, J.H.M.: Reality capture of buildings using 3D laser scanners. Civil Eng. **2**, 214–235 (2021). https://doi.org/10.3390/civileng2010012
25. SCHEDA TECNICA Caratteristiche principali Trimble TX8 (2013)
26. Pagano, N.: Using the intensity values obtained from terrestrial laser scanner for monitoring the effects of plant disease: the case study of Gorgognolo (Italy). In: Gervasi, O., et al. (eds.) Computational Science and Its Applications – ICCSA 2024. LNCS, vol. 14226, pp. 245–259. Springer, Cham (2024). https://doi.org/10.1007/978-3-031-65282-0_16