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# Economic and Social Impacts of Olive Quick Decline Syndrome: Analysing Data From the Italian Farm Accountancy Network

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## ABSTRACT

The rapid spread of *Xylella fastidiosa* subsp. *pauca* (Xfp) in the Salento area (Apulia region, southern Italy) has caused extensive socio-economic damage to the olive oil supply chain. This research evaluates the impact of the ‘Xfp treatment’ on selected economic and social variables using a counterfactual approach. We applied propensity score matching and the difference-in-difference estimator to a sample of Italian Farm Accountancy Data Network panel olive-growing farms. The study compared the outcomes of farms affected by the Xfp invasion before (2008–2012) and after (2017–2021), with a control group unaffected by Xfp. The results showed that the socio-economic performance of Salento’s olive-growing farms is lower than unaffected farms outside the region but comparable to similarly affected farms. Regarding the economic impact of Xfp, the Gross Operating Margin had an Average Treatment Effect on the Treated of around –€837 per hectare, indicating a reduction in profitability, amounting to a total loss of €132 million across the infected area. Social indicators also showed the effects of Xfp, evident in the reduction of total working hours and work units employed on Salento olive farms. The decrease was –7 h/ha, resulting in a total loss of 1,050,000 h across the entire infected area in Apulia (approximately 150,000 ha). These findings have policy implications, because they can assist policymakers in establishing a compensation budget for Apulian olive growers affected by Xfp. Identifying fair compensation is crucial for providing financial and technical support to help farmers convert their crops or adopt alternative agricultural practices.

## 1 | Introduction

### 1.1 | Current State of Olive Cultivation in Apulia

In Apulia (southern Italy), extra virgin olive oil stands as a symbol of global gastronomic distinction and serves as a cultural cornerstone (Lombardi et al. 2021), deeply interwoven with the region’s identity through its centuries-old tradition of olive cultivation. Notably, this sector plays a pivotal role in the regional

economy, yielding a turnover of approximately €600 million, constituting 16% of the total value of saleable agricultural production in Apulia. Furthermore, in 2008, Apulian olive growing accounted for 45% of Italian olive oil production, underscoring its substantial contribution to the national olive oil industry (ISTAT 2023). Salento area, located in the southern part of Apulia region (Figure 1), is known for its rich cultural heritage, stunning landscapes and historical significance. Economically, agriculture, particularly olive oil production, plays a significant role.

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**FIGURE 1** | Geographical Italian location of the Apulia region, including the Salento area. Located in the southeastern region of Italy, Apulia forms the heel of the Italian boot. The Salento area in Apulia is characterised by its unique agro-ecological features, which contribute to its agricultural productivity and biodiversity. This area has faced challenges with the spread of *Xylella fastidiosa* subsp. *pauca* (Xfp) that causes olive quick decline syndrome, affecting olive groves. The landscape of Salento is marked by rolling hills, olive groves, vineyards and coastal areas, creating a picturesque environment that supports both agriculture and tourism. Farmers in Salento combine traditional agricultural practices with modern techniques to maintain productivity and sustainability. Practices such as crop rotation, organic farming and integrated pest management are common. Salento experiences hot, dry summers and mild, wet winters, typical of the Mediterranean climate. This climate is conducive to growing a variety of crops, especially olives, grapes and cereals. [Colour figure can be viewed at [wileyonlinelibrary.com](https://onlinelibrary.wiley.com/doi/10.1111/jppa.14069)]



**FIGURE 2** | Olive quick decline syndrome disease in the Apulia region (southern Italy). This figure highlights the detection of *Xylella fastidiosa* subsp. *pauca* (Xfp) in olive trees in this region. The bacterium causes olive quick decline syndrome, which leads to severe symptoms such as leaf scorch, wilting and dieback. [Colour figure can be viewed at [wileyonlinelibrary.com](https://onlinelibrary.wiley.com/doi/10.1111/jppa.14069)]

The olive value chain is crucial to Salento's economy and environment, encompassing activities from olive cultivation to processing and distribution. The olive oil industry is a cornerstone of the Mediterranean economy, with Salento contributing significantly to Italy's production. For the 2023/2024 crop year, Italy's total olive oil production was approximately 289,000t, with Apulia (Salento) producing 201,800t, Sicily 37,292t and

Calabria 33,300t. The average price of olive oil in 2023 was €915 per 100kg, with a price increase of over 100% compared to the previous year. The market trends indicate a 9.5% increase in total sales for 2024, with domestic growth (10.4%) outpacing international markets (6.8%). The investment in this sector is expected to surge by 53.6%, with marketing spending rising from 0.3% of revenue in 2023 to 0.5% in 2024 (ISTAT 2023; Ozbun 2024).

However, the emergence of *Xylella fastidiosa* subsp. *pauca* (Xfp), a polyphagous xylem-limited bacteria transmitted by insect-vectors (El Handi et al. 2022; Kokiçi et al. 2024) has posed an unprecedented threat to Apulian olive groves, particularly in the Salento area. The devastating impact of this bacterium, leading to the olive quick decline syndrome (Figure 2), has resulted in extensive crop losses and a decline in oil quality. Table 1 provides a comparison of economic data between the Salento area and the national area before and after the invasion of Xfp.

## 1.2 | Review of Related Research

Few studies address similar research objectives. Sardaro et al. (2015) conducted a preliminary estimation of Xfp damage on olive orchards in the studied region. Using an income approach based on lost earnings, the damage was estimated to range from €111 to €119 per tree, with an additional 31% increase in costs. Cardone et al. (2021, 2022) used a socio-economic risk assessment technique, identifying Mediterranean countries,

**TABLE 1** | Economic data comparison between Salento area and National areas before and after *Xylella fastidiosa* subsp. *pauca* (Xfp) invasion.

Variable	Unit	Salento area	National area
Before Xfp invasion (average period of 2008–2012)			
Farm size	ha	36	16
Gross saleable production	€/ha	2379	5673
Gross operating margin	€/ha	1205	3416
Total revenues	€/ha	2565	5849
Total net income	€/ha	968	3058
Variable costs	€/ha	1297	2062
Fixed costs	€/ha	320	737
After Xfp invasion (average period of 2017–2021)			
Farm size		32	19
Gross saleable production	€/ha	1878	3885
Gross operating margin	€/ha	976	2026
Total revenues	€/ha	2116	4089
Total net income	€/ha	805	1845
Variable costs	€/ha	1029	1719
Fixed costs	€/ha	380	742

Note: Salento and other regions present different environmental, social and economic contexts that affect the data. Factors like soil quality, water availability and microclimate conditions can vary significantly. Economic data are compared over the same times to account for fluctuations and trends. The Xfp pathogen might not be present in other regions, affecting the economic performance comparison. The differences in variable costs (like labour, inputs and energy) between regions were considered, in which Salento's specific agricultural practices might differ from national averages.

Source: ISTAT (2023).

particularly Albania, as presenting the highest risk. White et al. (2020) developed a Bayesian method to estimate the epidemiological parameters of bacterial transmission, finding that each infected tree could infect approximately 19 trees per year. The social importance of Apulian olive growing has been highlighted in other studies. For instance, Frem, Santeramo, et al. (2021) reported that most residents in Foggia, Bari and Lecce expressed a strong desire to restore the landscape affected by Xfp. In Lebanon, a partial budget approach for the Lebanese winery estimated a potential gross revenue loss of \$11 million in the event of full deployment of Xfp (Choueiri et al. 2023; Frem, Fucilli et al. 2021). Pierce's disease (PD) has been the first significant Xfp disease to be studied, and is currently the focus of many established and new research threads (Raparelli et al. 2024). PD has caused significant damage to wine grape crops in several regions globally, including the United States, Brazil and Spain, where it was detected in 2017 in a vine in Mallorca, causing PD. Citrus variegated chlorosis in Brazil has led to substantial economic losses in the citrus agrifood sector, with researchers

observing variable host responses to bacterial colonisation and disease development (Habib et al. 2016; Niza et al. 2015).

In a study by Moralejo et al. (2019), the incidence and severity of PD were evaluated, and vector transmission experiments were conducted. Vineyards managed with conventional viticulture practices had significantly lower infection rates compared to those using organic farming methods. Meanwhile, the Apulian nursery industry has faced significant challenges in productivity and profitability, largely due to restrictions on the export of plants from areas affected by Xfp (Frem et al. 2024). Nurseries are particularly risky as they pose a threat of introducing and spreading quarantine pests like Xfp into uninfected areas. Further financial data on ornamental production costs and turnover, provided by Frem et al. (2022), help evaluate the economic feasibility and sustainability of innovative and sustainable production models. Bozzo et al. (2022) explored the interdependent relationships between the landscape and the biological invasion of Xfp. They investigated the differentiation between landscape and vegetation heterogeneity using five indicators: (a) vegetation index, (b) cultivation intensity, (c) cultural diversity, (d) density of agricultural landscape elements and (e) altitudes. These indicators serve as potential markers for spatial segmentation in the biological invasion process and for characterising the management costs of disease control. Other researchers continue to explore strategies to mitigate the economic and productive damage inflicted on olive trees, with a particular focus on replacing vulnerable crops with resilient varieties. A recent study by Walker et al. (2023) examined the significance of xylem geometry in conferring resistance to Xfp. Their findings indicate that susceptible cultivars, characterised by a higher proportion of larger vessels, are more prone to air embolisms. Under specific pressure conditions, the functional vascular system in susceptible olive cultivars may experience greater stress compared to their resistant counterparts. For instance, the local cultivars Cellina di Nardò and Ogljarola Salentina have exhibited heightened sensitivity to the Xfp strain De Donno (Xfp-DD). Due to these vulnerabilities, the choice of varieties for replanting is currently limited to FS 17 and Leccino cultivars, as determined by the Director of the Section of the Puglia Region on 4 May 2018. This decision is grounded in Article 8, paragraph 2 of the Ministerial Decree of 13 February 2018, which implements the EU Implementing Decision 2017/2352 (MASAF 2018). Both Leccino and FS 17 exhibit excellent adaptability to the typical soil and climate conditions of Salento. The Leccino cultivar is widely cultivated throughout Salento and has consistently shown resilience, with no signs of physiological difficulties or particular susceptibility to pests that attack olive trees. On the other hand, FS 17, although less prevalent, is derived from the widely grown Frantoio cultivar. Despite its limited presence, the behaviour and adaptability of FS 17 are positively evaluated, considering its lineage from the Frantoio variety. Furthermore, the Leccino cultivar has displayed traits of resistance to the bacterium. Unlike susceptible cultivars, the Leccino cultivar has occluded vessels predominantly filled with callose-like granules, effectively trapping Xfp-DD cells. Additionally, the Leccino cultivar boasts a compact structure that remains intact and impermeable to Xfp-DD (Montilon et al. 2023). Although Xfp is undoubtedly a significant factor, various other variables can profoundly influence yield, including soil quality, water availability (Giannoccaro et al. 2022), microclimate conditions

and the use of micronutrients. Disparities in soil composition and water availability can significantly impact olive yields. The soil in the Salento area may exhibit different nutrient levels and water retention capabilities compared to other regions in Italy. The microclimate, encompassing temperature, humidity and sunlight, can vary significantly across regions, influencing olive growth and productivity. Additionally, the absence of essential micronutrients in the soil can adversely affect tree health and yield. Although some growers may supplement these nutrients, these factors are not consistently factored into variable costs, despite their potential to significantly impact the economic outcomes of olive production (D'Attoma et al. 2019).

### 1.3 | Rationale for Research on *X. fastidiosa* Impact

Given the profound social, environmental and economic ramifications of the Xfp invasion in Apulia, this study aims to conduct an economic and social evaluation. The objective was to identify the disparity in economic performances between olive farms in Salento area and other Italian olive farms, while also assessing the economic and social impacts of the Xfp invasion. This is particularly important due to the significant gap in the literature on this topic. In fact, to the best of our knowledge, no study has ever been conducted on evaluating, through statistical methodology, the effects of the invasion or treatment of Xfp on the social and economic indicators of olive farms present in the Salento area. Based on the Farm Accountancy Data Network (FADN) data, our research aims to fill this gap by statistically validating the socio-economic performances of olive growers in Salento who have been adversely affected by Xfp, in comparison to their counterparts across Italy.

Propensity score matching (PSM) and difference-in-difference (DiD) approaches were used for this purpose (Blundell and Costa Dias 2002; Dehejia and Wahba 2002; Smith and Todd 2005). In summary, we used PSM to match olive farms in the Salento area affected by Xfp with similar, unaffected farms across the rest of Italy. Subsequently, we used the DiD method to compare changes in economic and social aspects of olive farming before and after the Xfp invasion. As such, the originality of this research lies in the methodological rigour and comprehensive insights gained by combining these powerful approaches, offering a unique and robust perspective for several reasons: (a) enhancing validity and reliability: PSM reduces selection bias by matching treated and control units on covariates, creating a balanced comparison, whilst DiD controls for unobserved time-invariant factors by comparing changes over time between treatment and control groups; (b) comprehensive analysis: PSM addresses confounding variables and ensures comparability, while DiD accounts for changes over time, providing a thorough analysis of treatment effects. Combining both methods results in a more robust estimate of the treatment effect, enhancing the credibility of the findings and (c) novel contribution: using PSM and DiD in tandem is relatively novel and advances methodological approaches in research. This combination allows for deeper insights into causal relationships, especially in complex scenarios where simple observational or experimental methods may fall short. By using PSM, we match olive farms affected by Xfp with similar unaffected farms, ensuring a fair comparison. DiD analyses the changes in economic and social outcomes before

and after the Xfp invasion, offering a clearer picture of its impact over time. This provides valuable insights for policymakers and stakeholders to better support and sustain this essential agricultural sector. It also helps in offering fair financial aid and technical assistance, enabling affected farmers to switch crops or adopt alternative agricultural methods.

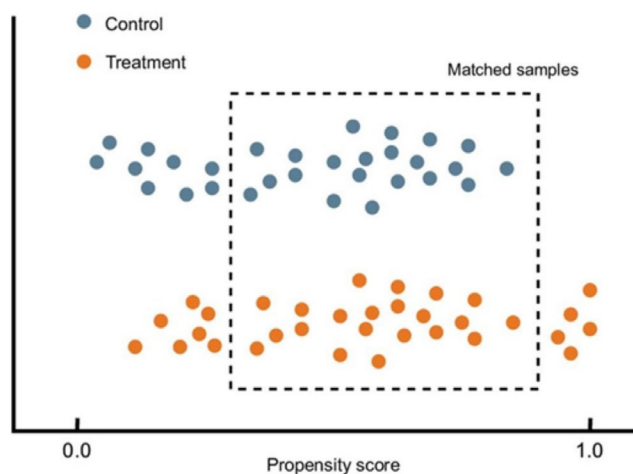
## 2 | Materials and Methods

### 2.1 | Propensity Score Matching

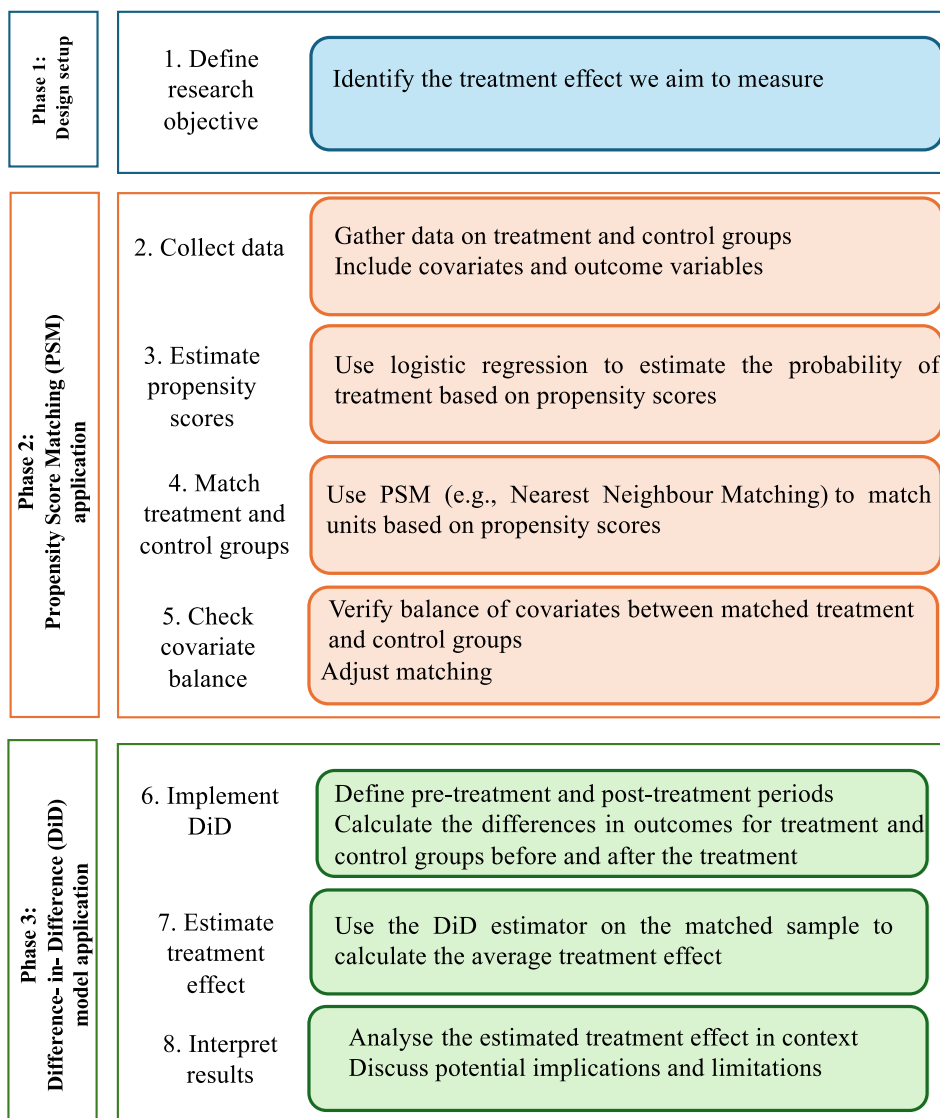
PSM, a well-established approach, is a statistical technique greatly used in observational studies to create a balanced comparison between a treatment group (i.e., those receiving an intervention) and a control group (i.e., those not receiving it) based on observed covariates. The PSM is used to reduce selection bias by matching units (i.e., individuals, farms) with similar propensity scores (PS). The latter is the probability of a unit receiving a treatment given a set of observed covariates. The aim is to construct a sample in which the treatment and control groups are comparable across all observed covariates, thereby replicating the conditions of a randomised experiment, as shown in Figure 3 (Luvsandorj 2023). To achieve this, we conducted the PSM and DiD in three phases and eight steps as highlighted in Figure 4.

#### 2.1.1 | Data Gathering, Covariates and Outcome Variables

We selected a comprehensive panel of 123 olive-growing farms (FADN 2021), present both before the invasion of Xfp (2008–2012) and subsequently (2017–2021). This selection encompassed a diverse range of households, ensuring a robust and representative sample for our study. We divided the farms into treated



**FIGURE 3** | An example of propensity score matching (PSM) using nearest neighbour matching. Samples are matched based on their propensity score similarity, also called Propensity Score (PS) distance. The dotted box highlights matched samples, where the propensity scores of the two groups are similar, indicating that these samples were selected for direct comparison between the treated (i.e., olive farms impacted by *Xylella fastidiosa* subsp. *pauca* [Xfp] in the Salento area) and control groups (i.e., similar farms unaffected by Xfp in other Italian regions). [Colour figure can be viewed at [wileyonlinelibrary.com](https://onlinelibrary.wiley.com)]



**FIGURE 4** | An overview of the propensity score matching (PSM) and difference-in-difference (DiD) approaches. The diagram highlights the steps in each phase of the PSM and DiD that were considered in our research, in which step 1 is described in Section 1. [Colour figure can be viewed at [wileyonlinelibrary.com](https://onlinelibrary.wiley.com)]

farms, invaded by Xfp (Salento area) and untreated farms, not invaded by Xfp (the rest of Italy). According to the FADN, 31 of 123 olive-growing farms are present in the Salento area (treated group) and 92 are olive-growing farms present throughout the national territory excluding Salento (control group). We then gathered data on treatment and control groups, including independent variables (covariates) and dependent variables (outcomes) as described in Tables 2 and 3, respectively.

With regard to covariates, we identified total cultivated area, mode of cultivation (specifically organic farming), farm diversification and economic dimension as the key covariates most relevant to our research objectives (Table 2). These factors are expected to significantly influence both the outcomes and the treatment assignment, ensuring the comparability between the treatment and control groups. The size of the farm can affect the spread of Xfp, as larger areas may be more challenging to monitor and manage effectively. Additionally, larger farms often host a greater diversity of plant species, which can either facilitate the spread of the pathogen or provide a buffer through crop diversification.

Organic treatments, when combined with good agricultural practices, have shown promise in managing Xfp. For example, the use of compounds such as zinc, copper and citric acid has proven effective in reducing symptoms and bacterial populations in olive trees. Crop diversification emerges as a crucial strategy in managing Xfp. By planting different types of crops, farmers can create a less favourable environment for the pathogen and its vectors, thereby potentially reducing the spread of the disease.

Concerning the outcome variables, we identified a total of six economic indicators and three social indicators, as detailed in Table 3. The careful selection and integration of these outcome variables within the PSM DiD model allows for a thorough analysis of the various dimensions impacted by the treatment, ensuring a well-rounded understanding of the effects on both economic performance and social dynamics within the olive-growing farms and providing an accurate and comprehensive analysis of the treatment's impact. By encompassing both economic and social dimensions, the model provides a comprehensive view of the treatment's impact, facilitating a thorough understanding of its

**TABLE 2** | Independent variables (covariates) used in the propensity score matching (PSM) model.

Variable	Code	Category	Rationale
Treatment variable	TR	The Treatment variable is an independent dichotomous variable with two values: 0 and 1. Farms in the Salento area infected by Xfp are assigned the value 1, while Italian farms outside the Salento area, not infected by Xfp, are assigned the value 0	In propensity score matching, the Treatment variable is crucial because it defines the groups being compared: treated (infected) versus untreated (not infected). By controlling for the Treatment variable, the model aims to create comparable groups to estimate the treatment effect of Xfp infection in the Salento area. Essentially, it allows for a clearer understanding of how the treatment influences the outcome, minimising bias from confounding variables
Total cultivated area	TA	The total cultivated area is an independent variable representing the agricultural land dedicated to and covered with olive trees	Larger farms may have more resources to implement effective management practices and control measures against Xfp. However, they also present a larger area that could potentially be affected by the pathogen
Mode of cultivation, organic farming	BIO	The organic variable is an independent, dichotomous variable that can take on two values: 0 and 1. Organic farms are assigned a value of 1, while non-organic farms are assigned a value of 0	Organic farming methods typically avoid synthetic pesticides and fertilisers, relying on natural alternatives. This can impact the prevalence and management of Xfp
Farm diversification	DIVE	The diversification variable is an independent, dichotomous variable that can take on two values: 0 and 1. A value of 1 indicates diversified farms that present a variety of crops and services for complementary activities while a value of 0 represents non-diversified farms	Diversification involves growing a variety of crops rather than a single type. This can reduce the risk of widespread infection by limiting the pathogen's ability to spread, enhance soil health and improve farm resilience
Economic dimension	DE	The economic dimension is an independent, nominal variable representing the economic size of the farms. It is categorised into five levels: 1. Small: <€4000 2. Medium-small: €4000–€8000 3. Medium: €8000–€25,000 4. Medium-large: €25,000–€50,000 5. Large: >€50,000	The economic dimension involves analysing the financial aspects of farming, including income, costs, profitability and economic viability. The economic impact of Xfp includes costs related to crop losses, management practices and potential job losses in the agricultural sector

Abbreviation: Xfp, *Xylella fastidiosa* subsp. *pauca*.

consequences. Properly selecting outcome variables helps to control for confounding factors, thereby reducing bias and ensuring that the observed effects are genuinely attributable to the treatment. The inclusion of diverse and relevant outcome variables strengthens causal inferences, making the findings more robust and actionable for policy and decision-making.

### 2.1.2 | Propensity Score Estimate

An important step in PSM concerns the estimation of the PS, ranging from 0 to 1 (Figure 3), and representing the probability that a unit (such as a farm) will receive the 'treatment', based on selected covariates (Table 2) using a logistic regression model (Table 4). A score of 0 indicates no likelihood, and a score of 1 indicates a very high likelihood of the farm being affected by Xfp, given the covariates. These scores facilitate the matching of farms with similar propensities, ensuring a fair comparison between treated and control groups. As a result, differences in

outcomes can be more confidently attributed to the treatment (Xfp impact) rather than other confounding factors.

### 2.1.3 | Treatment and Control Group Matching

There are various matching methods available in the literature, each offering distinct advantages and disadvantages. These methods include 'nearest neighbour matching' (NNM), 'radius matching', 'kernel matching' and 'stratification matching' (Caliendo and Kopeinig 2008). In our study, we used the NNM technique to pair infected and non-infected farms based on similar PS. This approach allowed us to effectively apply the DiD method to minimise the influence of trends in the independent variables. By closely matching farms with similar PS, we enhanced the comparability of the treatment and control groups, thereby improving the reliability of our estimated treatment effects. This meticulous matching process is crucial for ensuring the validity and robustness of our findings.

**TABLE 3** | Dependent variables (outcomes per 1 ha) used in the propensity score matching (PSM) difference in difference model.

Variable	Code	Category	Rationale within PSM model
Economic variables			
Gross operating margin	GOM	GOM is a dependent variable and an economic indicator used in the sample, calculated by subtracting labour costs from added value. It measures farm profitability	This analysis clarifies how Xfp infection influences farm profitability, providing insights for economic and agricultural decision-making
Gross salable production	GSP	GSP is a dependent variable and an economic indicator in the sample. It represents revenues strictly tied to agricultural activities	This approach clarifies how Xfp infection influences agricultural revenue, aiding economic and agricultural policy decisions
Total revenue	TR	TR is a dependent variable and an economic indicator in the sample. It represents revenue obtained from selling quantities at market prices	This analysis elucidates how Xfp infection influences total revenue, providing valuable insights for economic and agricultural decision-making
Total net income	TIN	TIN is a dependent variable and an economic indicator in the sample. TIN represents the amount of money remaining after subtracting all costs and expenses from total earnings	This analysis clarifies how Xfp infection affects overall profitability, providing insights into the economic impact on agricultural operations
Variable costs	VC	VC is a dependent variable and an economic indicator in the sample. It represents the sum of current costs and temporary labour costs	This analysis clarifies how Xfp infection influences variable costs, providing insights into the economic impacts on agricultural operations
Fixed costs	FC	FC is a dependent variable and an economic indicator in the sample. It represents fixed costs, which are the sum of multiyear costs and the cost of non-adventitious labour	This analysis clarifies how Xfp infection influences fixed costs, providing insights into the economic impact on agricultural operations
Social variables			
Total working hours	TWH	TWH is a dependent variable and a social indicator in the sample. It includes labour exchange between farms, excluding passive subcontracting	This analysis clarifies how Xfp infection affects labour allocation and exchange, providing insights into the social impact on agricultural operations
Work units	WU	WU refers to quantifiable measures of labour or workforce effort involved in specific tasks or processes within a study or analysis. These units can be used to assess and compare the productivity, efficiency and labour allocation between treated and control groups	The rationale for including working units in PSM DiD model is to ensure that the matching process accounts for differences in labor input, which could otherwise confound the estimated treatment effect. By controlling for working units, we can more accurately isolate the effect of the treatment from other factors related to labour effort, leading to more valid and reliable causal inferences
Family work units	FWU	FWU is a dependent variable and a social indicator in the sample. It considers the labour contributed by family members within the farm	This analysis clarifies how Xfp infection affects family labour contributions, providing insights into the social impact on agricultural operations

Abbreviation: Xfp, *Xylella fastidiosa* subsp. *pauca*.

### 2.1.4 | Covariate Balance Checking

Checking covariate balance is a crucial step in the PSM process. Ensuring covariate balance is fundamental to the credibility and reliability of PSM analyses, making this step indispensable in the pursuit of valid causal estimates. After

matching treated and control units based on their PS, it is essential to verify that the covariates are balanced between the two groups. This means that the distributions of covariates should be similar in both the treatment and the control groups, ensuring that any observed differences in outcomes can be attributed to the treatment effect rather than pre-existing

**TABLE 4** | Descriptive statistics for both the independent ( $X$ ) and dependent ( $Y$ ) variables.

Variable	Mean	Median	1st quartile	3rd quartile	Min.	Max.
Independent variables ( $X$ )						
Treatment (TR)	0.25	0	0	0.5	0	1
Organic (BIO)	0.33	0	0	1	0	1
Total area (TA)	23.30	11.29	6.81	19.28	2.32	332.30
Farm diversification (DIVE)	0.09	0	0	0	0	1
Economic dimension (DE)	1.87	1.8	1	2	1	5
Dependent variables ( $Y$ ) (economic indicators)						
Gross operating margin ( $\Delta$ _GOM)	746.2	565	-314.8	1478.8	-5162.4	7611.9
Gross salable production ( $\Delta$ _GSP)	1210.4	902.4	-246.0	2795.6	-7251.5	8619.3
Total revenues ( $\Delta$ _TR)	1133.0	897.9	-281.5	2795.7	-7251.5	8619.3
Total net income ( $\Delta$ _TIN)	467.1	271.4	-600.6	1304.1	-5792.8	7127.5
Variable costs ( $\Delta$ _VC)	404.0	368.0	-119.7	972.6	-3765.0	3240.6
Fixed costs ( $\Delta$ _FC)	-1065.0	-954.8	-1763.4	-335.7	-4438.5	3474.1
Dependent variables ( $Y$ ) (social indicators)						
Total working hours ( $\Delta$ _TWH)	38.34	27	-10.01	89.49	-270.42	377.18
Work units ( $\Delta$ _WU)	0.02008	0.01	0.00	0.045	-0.13	0.19
Family work units ( $\Delta$ _FWU)	0.00536	0	-0.010	0.020	-0.10	0.12

differences in covariates. The rationale for checking and ensuring covariate balance within the PSM approach is to reduce bias and improve the validity of causal inferences. When covariates are balanced, the treatment effect estimates are less likely to be confounded by differences in baseline characteristics between treated and control units. This makes the comparison more akin to a randomised controlled trial, where the only systematic difference between groups is the treatment itself (Caliendo and Kopeinig 2008).

## 2.2 | Difference-In-Difference

To effectively implement the DiD approach, we defined the pre-treatment and post-treatment periods. The pretreatment period (2008–2012) refers to the time before the treatment or intervention is implemented, serving as a baseline to measure subsequent changes. The post-treatment period (2017–2021), on the other hand, is the time following the implementation of the treatment or intervention, allowing for the assessment of its impact. Next, we calculated the difference in outcomes (Table 3) for both the treatment and the control groups. For the treatment group, this involved computing the average outcome in the post-treatment period and subtracting the average outcome in the pretreatment period. Similarly, for the control group, we calculated the average outcome in the post-treatment period and subtract the average outcome in the pretreatment period. Finally, the DiD estimators are used to assess the treatment effect by taking the difference between the changes in outcomes for the treatment and control groups, thereby providing a more accurate estimate of the treatment's impact. As such, two terms can be calculated:

the 'average treatment effect' (ATE) and the 'average treatment effect on the treatment' (ATT). The first term refers to differences in outcomes before and after treatment for the entire population. So, the ATE approach measures the average impact of the Xfp invasion on Italian olive farms, comparing those in the Salento area (1) with those outside (0):

$$ATE = E(Y^1 | T = 1) - E(Y^0 | T = 0), P(X)$$

where  $Y^1$  represents the outcome variable for farms experiencing the invasion, and  $Y^0$  represents the same variable without the invasion.  $T$  is a binary variable that identifies whether a farm belongs to the treated group ( $T=1$ ) or not ( $T=0$ ).  $P(X)$  represents the estimated probability of being treated given a set of observable characteristics  $X$ . This probability is also called PS. It serves to balance the treated and control groups, that is, to ensure that they are comparable in terms of the observable characteristics. The  $E$  operator calculates a weighted or conditional mean, so as to isolate the effect we are interested in studying (in this case, the treatment effect), eliminating variability due to other factors.

By comparing these outcomes for both treated (infected) and untreated (uninfected) farms, both before and after the Xfp infection, we can determine the average effect of the invasion. This approach highlights the economic and social distress primarily affecting the Salento farms but it can be distorted if there are time trends. The counterfactual approach of the DiD is applied through the calculation of the ATT on the treated and matched groups, considering both the ex-post and the ex-ante differences between the two. The ATT represents the difference between

the treated outcomes and the treated outcomes observed if they had not been treated:

$$ATT = \{E(Y_t^1 - Y_s^0 | T = 1, P(X)) - E(Y_t^0 - Y_s^0 | T = 0, P(X))\}$$

where  $t$  represents a time period after the programme's starting date and  $s$  a time period before its implementation. The ATT measures the impact of the Xfp invasion specifically on olive farms in Salento (the treated group, coded as 1). By comparing these farms to those outside Salento (coded as 0), the ATT reveals how the Salento olive farms would have performed had they not been affected by the invasion. This provides a nuanced understanding of the specific effects of Xfp on treated farms, contrasting their outcomes with both their own pretreatment performance and the performance of untreated farms.

### 3 | Results

#### 3.1 | Descriptive Statistics

The descriptive statistics presented in Table 4 provide insightful details about the distribution and characteristics of both the independent ( $X$ ) and the dependent ( $Y$ ) variables. The Treatment (TR) variable indicates that 25% of the farms were treated with Xfp, suggesting a significant skew towards untreated farms, while 33% of the farms practised organic farming. The Total Area (TA) variable shows considerable variation, with a mean area of 23.3 ha, highlighting the diversity in farm sizes. Interestingly, the Farm Diversification (DIVE) variable suggests low diversification among the farms, with a mean of 0.09. The Economic Dimension (DE) indicates that most farms are small to medium-sized, with a mean value of 1.87.

The economic indicators reveal a mixed performance among farms. The Gross Operating Margin ( $\Delta\_GOM$ ) and Total Net Income ( $\Delta\_TIN$ ) show a positive mean but a negative median, indicating that while some farms are profitable, many are operating at a loss. Similarly, the Gross Saleable Production ( $\Delta\_GSP$ ) and Total Revenues ( $\Delta\_TR$ ) have positive means, highlighting the variability and financial challenges faced by farms. Variable Costs ( $\Delta\_VC$ ) and Fixed Costs ( $\Delta\_FC$ ) show that farms incur significant costs, with  $\Delta\_VC$  having a positive mean and  $\Delta\_FC$  a negative mean, reflecting the financial burden of maintaining operations.

Social indicators also provide a nuanced picture. Total Working Hours ( $\Delta\_TWH$ ) and Work Units ( $\Delta\_WU$ ) show that farms

experience varying labour demands, with some reducing working hours and others increasing them. Family Work Units ( $\Delta\_FWU$ ) indicate a slight reduction in family labour contributions, which may affect overall farm productivity.

In summary, the results reveal a complex landscape for olive farms affected by Xfp, characterised by significant economic variability and labour dynamics. The findings underscore the need for targeted interventions to support affected farms, particularly those struggling with profitability and labour challenges. Understanding these dynamics can help shape effective policies and strategies to mitigate the impact of Xfp and promote sustainable agricultural practices.

#### 3.2 | Propensity Score Estimates

Table 5 reveals the PSM estimates in which the intercept has an estimate of  $-0.724$  with a standard error of 0.571. The  $z$ -value is  $-1.268$  and the  $p$ -value is 0.204, indicating that it is not statistically significant at the common levels (90%, 95%, 99%). The total cultivated area (TA) has an estimate of 0.015 with a standard error of 0.006. The  $z$ -value is 2.434 and the  $p$ -value is 0.014, showing statistical significance at the 95% level. This suggests a positive relationship between the total cultivated area and the probability of receiving the treatment (Xfp impact). Regarding the mode of cultivation (BIO), for organic farming, the estimate is 1.149 with a standard error of 0.480. The  $z$ -value is 2.393 and the  $p$ -value is 0.016, which is significant at the 95% level. This indicates a positive association between organic farming and the likelihood of Xfp impact. With respect to the farm diversification (DIVE), the estimate is  $-0.232$  with a standard error of 0.794. The  $z$ -value is  $-0.293$  and the  $p$ -value is 0.769, showing no statistical significance. This suggests no strong relationship between farm diversification and the probability of receiving the treatment. Concerning the economic dimension (DE), this variable has an estimate of  $-0.633$  with a standard error of 0.340. The  $z$ -value is  $-1.863$  and the  $p$ -value is 0.062, indicating marginal significance at the 90% level. This suggests a negative relationship between the economic size of the farm and the likelihood of being impacted by Xfp. As a result, TA and BIO are significant predictors of Xfp impact, while DIVE is not. The DE shows marginal significance, suggesting that larger economic size may reduce the likelihood of Xfp impact due to several potential reasons and mechanisms, such as larger economic farms typically having more resource availability at their disposal. These resources can be allocated towards (a) research and development, that is, investing in advanced technologies

**TABLE 5** | Propensity score matching (PSM) estimate using an R logistic regression model.

Variable	Code	Estimate	SE	$z$	Pr (>   $z$  )
(Intercept)		-0.724	0.571	-1.268	0.204
Total cultivated area	TA	0.015	0.006	2.434	0.014*
Mode of cultivation, organic farming	BIO	1.149	0.480	2.393	0.016*
Farm diversification	DIVE	-0.232	0.794	-0.293	0.769
Economic dimension	DE	-0.633	0.340	-1.863	0.062

\*Significant at  $\geq 90\%$ .

and methods to detect and control Xfp; (b) infrastructure, that is, building better physical infrastructure that may help in monitoring and managing the spread of Xfp; and human resources, that is, using skilled personnel who are capable of effectively implementing control measures and innovative solutions. In addition, economically larger farms usually possess greater financial stability, allowing them to better withstand economic losses due to Xfp outbreaks, quickly mobilise funds for emergency interventions to contain the outbreak, and to invest in insurance policies that can mitigate the financial impacts of Xfp. Moreover, economically robust farms often have better access to superior information and data management systems that facilitate timely decision-making and response strategies and use of cutting-edge technologies for early detection, diagnosis and treatment of Xfp. Furthermore, economically stronger farms often have stronger networks with other organisations and stakeholders that can aid in collective action against Xfp, and established partnerships with research institutions, government agencies and international organisations for coordinated efforts.

### 3.3 | Propensity Score Matching Balance

The PSM balance results (Table 6) reveal significant improvements in matching treated (infected by Xfp) and control (not infected by Xfp) farms by total area. Initially, treated farms had a mean total area of 40.10 ha, compared to just 17.70 ha for control farms, indicating a substantial imbalance. After matching, the mean total area for control farms increased to 28.28 ha, aligning more closely with the treated farms. The standardised mean difference decreased notably from 28.27 to 14.92, showcasing enhanced comparability. Furthermore, the *t* test *p*-value shifted from 0.13 to 0.050, nearing statistical significance, which underscores the effectiveness of the matching process in reducing bias and creating a more equivalent control group. This improved balance strengthens the validity of the analysis and the ability to draw meaningful conclusions about the impact of Xfp on farm size.

### 3.4 | Difference-In-Difference and Average Treatment Effect

Table 7 provides a comprehensive analysis of the ATT for several economic and social variables, highlighting the significant ramifications of Xfp infection on olive farms. Notably, Xfp infection led to a significant reduction in the gross operating margin ( $\Delta\_GOM$ ) by 837.15, with a *p*-value of 0.034, and a substantial decrease in total net income ( $\Delta\_TIN$ ) by 878.0 (Figure 5), evidenced by a *p*-value of 0.011. Total revenues ( $\Delta\_TR$ ) also experienced a significant decline of 1006.10, with a *p*-value of 0.038, indicating that Xfp infection severely impacted the financial performance of infected farms. Social indicators also showed the effects of Xfp, evident in the reduction of total working hours and work units employed on Salento olive farms. The decrease was  $-7$  h/ha, resulting in a total loss of 1,050,000 h across the entire infected area in Apulia ( $\sim 150,000$  ha).

Conversely, the results showed that gross saleable production ( $\Delta\_GSP$ ), variable costs ( $\Delta\_VC$ ), fixed costs ( $\Delta\_FC$ ), total

**TABLE 6** | Propensity score matching balance.

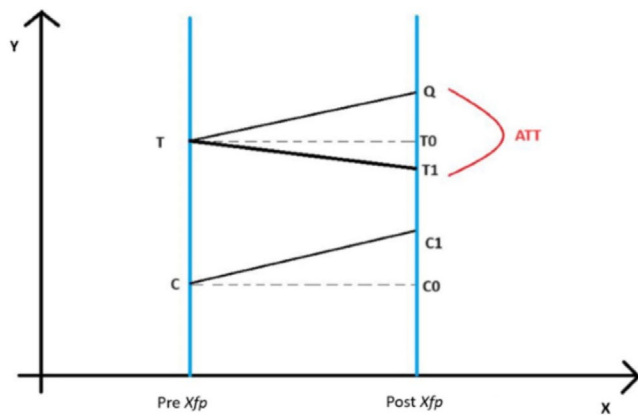
Total area	Before matching	After matching
Mean treatment	40.10	40.10
Mean control	17.70	28.28
Standard mean difference	28.27	14.92
<i>t</i> test <i>p</i> -value	0.13	0.050

**TABLE 7** | Estimating the average treatment effect on the treated (ATT) for economic and social variables (*Y*) of treated farms.

Variable	ATT estimate	AI SE	<i>t</i> statistic	<i>p</i>
Gross operating margin ( $\Delta\_GOM$ )	-837.15	395.0	-2.119	0.034
Gross saleable production ( $\Delta\_GSP$ )	-745.19	479.5	-1.553	0.120
Total revenues ( $\Delta\_TR$ )	-1006.10	486.5	-2.068	0.038
Total net income ( $\Delta\_TIN$ )	-878.0	347.5	-2.526	0.011
Variable costs ( $\Delta\_VC$ )	-109.2	263.1	-0.415	0.677
Fixed costs ( $\Delta\_FC$ )	77.53	417.01	0.185	0.852
Total working hours ( $\Delta\_TWH$ )	-7.046	26.58	-0.265	0.790
Work units ( $\Delta\_WU$ )	-0.004	0.013	-0.312	0.754
Family work units ( $\Delta\_FWU$ )	0.008	0.009	0.868	0.384

Abbreviation: AI SE, Abadie-Imbens standard error.

working hours ( $\Delta\_TWH$ ), work units ( $\Delta\_WU$ ) and family work units ( $\Delta\_FWU$ ) were not significantly affected, as reflected by their higher *p*-values, which did not meet conventional significance thresholds. These findings illustrate the profound economic distress caused by Xfp, primarily affecting profitability metrics, while other operational and labour-related variables remained relatively stable. The significant downturn in financial indicators necessitated targeted economic support and intervention strategies to alleviate the burden on Xfp-affected farms, ensuring their sustainability and resilience in the face of this agricultural challenge. In fact, the economic support can facilitate the adoption of sustainable agricultural practices that are less susceptible to Xfp. The intervention strategies, including training and support programmes, can build resilience, helping farms adapt to and recover from future outbreaks.



**FIGURE 5** | Total net income based on a difference-in-difference (DiD) approach. This figure represents a time graph with two periods: pre-*Xylella fastidiosa* subsp. *pauca* (Xfp) invasion (2008–2012) and post-Xfp invasion (2017–2021). The x-axis represents time, while the y-axis indicates the variable called total net income (TIN). *T* and *C* represent the treatment group and the control group, respectively, in the pre-Xfp period. *T0* and *T1* indicate the values of the treated group in the two periods, while *C0* and *C1* indicate the values of the control group. *Q* represents a higher point than *T1*. *Q* is a variable *y* treatment group if it were not treated in the period after Xfp. The ATT (Average Treatment Effect on the Treated) indicates the average effect of the treatment between the two periods, measured as the difference between *T1* and *Q* between the treated group and the treated group if there had been no treatment. [Colour figure can be viewed at [wileyonlinelibrary.com](https://onlinelibrary.wiley.com/doi/10.1111/ppa.14409)]

## 4 | Discussion

### 4.1 | Main Findings at a Glance

The research findings indicate that the socio-economic performance of Salento's olive-growing farms significantly declined due to the invasion of Xfp. Using a counterfactual approach, we used PSM and the DiD estimator to analyse data from affected farms from 2008–2012 (pre-invasion) to 2017–2021 (post-invasion). In terms of economic impact, the Gross Operating Margin exhibited an ATT of approximately –€837 per hectare, leading to a total estimated loss of around €132 million across the affected area. In addition, a comparative analysis of economic data shows that the Salento area experienced a reduction in gross saleable production from €2379 per ha (pre-Xfp) to €1878 per ha (post-Xfp), while the national average also saw a decline but remained significantly higher at €3885 per ha. With respect to the social indicators, the labour market suffered as evidenced by a reduction of 7 working hours per hectare, translating into a staggering total loss of approximately 1,050,000 h across the 150,000 ha impacted in Apulia. This decline in labour not only affects economic viability but also contributes to social distress in rural communities reliant on olive farming.

### 4.2 | Analysis of Findings

In the present research, the counterfactual approach reveals that the most significant characteristics for matching the sample are the organic cultivation method and the total surface area. This finding suggests that the organic method may render

olive crops more susceptible to infection. There are two main reasons for this: (a) lack of chemical protection: conventional agriculture often uses synthetic fungicides and bactericides that directly target pathogens, whereas organic farming relies on natural compounds, which may be less effective in some cases. (b) Fewer agronomic practices: organic farming might involve fewer intensive agronomic practices, potentially leading to less immediate intervention when dealing with outbreaks. Consequently, poor phytosanitary and agronomic management of olive groves, together with the presence of other pathogens (e.g., fungi) that are not effectively combated, can compromise the vitality and increase the susceptibility of trees, leading to their death. In Salento, the lack of microelements such as zinc, copper and manganese in the soil is another predisposing factor for Xfp infection. These microelements are crucial in the interaction with Xfp, as they inhibit the formation of biofilm by the bacterium (Scortichini 2020). However, to counter these hypotheses, a group applied PSM, demonstrating that organic farming could increase the technical efficiency of olive trees, making them the best-performing farms (Raimondo et al. 2021). In the future, other sample *x*-variables, such as the age of the olive-growing farmer, could be considered to see how they would affect matching in the counterfactual approach. Enhanced soil organic matter and microbial activity can support plant growth and resilience. Older plants might have more established root systems and better nutrient uptake mechanisms, which can be advantageous in organic systems that rely less on synthetic fertilisers. Moreover, older plants might have developed more robust natural defences against pests and diseases, aligning well with organic farming's emphasis on natural pest control methods. Studies have shown that organic farming can lead to more stable yields over time, as soil health and plant resilience improve with age. The economic benefits of organic farming, such as premium prices for organic products, can increase with plant age as the plants become more productive and the soil ecosystem becomes more balanced.

Our study also reveals a significant loss in the net income per hectare of infected areas. Xfp negatively affects crop yields and quality, directly reducing the income from sales. Lower-quality produce fetches lower market prices, further diminishing revenues. Managing Xfp incurs additional costs, including increased expenditure on pesticides, fungicides and other disease management practices. These higher costs directly cut into profit margins. Infected farms may lose access to certain markets due to quarantine restrictions or reduced consumer demand for their products, impacting their revenue streams. By multiplying the effect of Xfp on this indicator by the entire infected area in Apulia (~150,000 ha), the impact amounts to –€132,000,000. According to a bio-economic model, the potential economic impact for Italy over the next 50 years ranges from €1.9 billion to €5.2 billion in the worst-case scenario. If replanting with resistant varieties were feasible, the impact would range between €0.6 billion and €1.6 billion (Schneider et al. 2020). Furthermore, the impact of the Xfp treatment on the main economic indicators of Salento farms is confirmed by ISTAT data, which report a negative trend in Apulian olive production for 2021 and 2022. The area cultivated with oil olives and the harvested production, expressed in quintals, have shown fluctuations probably caused by the spread of the Xfp bacterium. Over the past three years, Xfp has caused significant losses in the area cultivated

with oil olives throughout the Apulia region, especially in the provinces of Lecce and Taranto, the areas most affected by olive quick decline syndrome. As a result, the profitability of olive oil companies has been jeopardised. ISTAT has recorded significant fluctuations in the GOM indicator from 2013 to 2021. Specifically, since 2017, the GOM has decreased dramatically, from €1339/ha to €929/ha in 2021. The reduction in revenues, resulting from lower production yields, is primarily due to the decreased need for inputs (e.g., fertilisers, pesticides, fuels, etc.) for essential field operations such as pruning, fertilisation, pest management, irrigation and harvesting. This decrease in demand is based on the observed production loss per hectare per year. FADN data confirm the negative trend from 2010 to 2021 in specific costs, yields and gross saleable production. Regarding social indicators, the obtained results are presumably due to reduced demand for labour following lower production and cultivated areas. The impact on FWU indicates the re-employment of family labour to mitigate expenses and compensate for reduced earnings.

### 4.3 | Repercussions of Xfp on Olive-Growing Farms and Future Roadmap

These findings underscore the profound socio-economic repercussions of the Xfp invasion on the olive oil supply chain in the Salento area. The evidence suggests that the socio-economic status of Salento's olive farms is now inferior to unaffected regions, while being comparable to farms severely impacted elsewhere. These results signify that while the immediate economic impacts are detrimental, they also reflect systemic vulnerabilities in agricultural practices. In terms of policy implications, with the observed substantial economic losses and decline in work hours, there is a pressing need for policymakers to formulate effective compensation strategies for affected farmers. Efforts should focus on providing financial and technical support that not only compensates for losses but also encourages farmers to transition to alternative agricultural methods or diversified crops. Regarding the cultural and historical context, it is crucial to consider the cultural significance of olive cultivation in Apulia, as it represents an integral aspect of regional identity. The ongoing decline in the olive oil sector could further erode this heritage, necessitating urgent interventions to sustain both economic and cultural landscapes.

As such, the consequences of Xfp on olive-growing farms in the Salento region are profound and multifaceted, presenting both immediate and long-term challenges for the sector. Our analysis reveals not only a significant decline in the socio-economic performance of affected farms but also highlights the intricate link between agricultural health and the broader sociocultural fabric of the region. In this direction, the data clearly indicate that the socio-economic conditions of olive farms in Salento have deteriorated sharply over the years, with marked decreases in crop yields and overall profitability. The estimated losses ranging from €111 to €119 per plant underscore the economic strain placed on farmers, exacerbated by the mortality of 6.5 million olive trees and the direct impact on the production capacity of the region. This situation not only threatens the livelihoods of those directly involved in olive cultivation but also jeopardises the entire olive oil supply chain, which is a cornerstone of the Apulian economy.

Moreover, it is crucial to consider the broader implications of this agricultural crisis. The cultural significance of olive oil production in Apulia cannot be overstated. It is deeply embedded in the region's identity and traditions. The extensive loss of olive trees translates not just to economic disparity but to the gradual erosion of a cultural heritage that has persisted for centuries. This loss is echoed in community sentiments, where many residents express a desire to restore and rehabilitate the landscapes once thriving with olive groves. Thus, the sociocultural ramifications of Xfp extend beyond the realm of agriculture, highlighting the need for community-driven approaches in addressing this crisis.

Policy responses to the Xfp invasion must therefore go beyond mere financial compensation. While establishing a structured compensation budget is a critical first step, the creation of comprehensive support systems that include technical guidance, access to resistant varieties and training in sustainable agricultural practices are essential. Investing in research initiatives that explore resistant cultivars, such as the promising traits identified in the Leccino variety, will be vital in developing adaptive strategies for affected farmers. Furthermore, the economic impacts of Xfp are compounded by the challenges faced in nurseries and the ornamental plant sector, as restrictions on plant exports from infected regions present additional financial hurdles. Addressing the broader agricultural ecosystem, including nurseries and related industries, is imperative to safeguarding economic viability in the face of ongoing infection risks from Xfp.

With respect to future directions, further research is needed to understand the long-term impacts of Xfp on agricultural practices and rural economies. Studies like those conducted by Sardaro et al. (2015) and Frem et al. (2021) provide a foundation for understanding the broader socio-economic risks of similar agricultural challenges. The roadmap forward necessitates a holistic approach, one that integrates economic recovery efforts with environmental sustainability and cultural preservation. Collaborative efforts among policymakers, researchers, agricultural practitioners and local communities will be essential in redefining agricultural models that can withstand the pressures posed by emerging plant pathogens like Xfp.

### 4.4 | Conclusion

The spread of the bacterium Xfp has resulted in reduced agricultural production and job losses, leading to significant economic and social repercussions. Furthermore, it has harmed ecosystem services such as landscape conservation, which indirectly impacts the society, traditions and economy of Apulia. As traditional agricultural practices are lost alongside the olive groves, there is a risk of losing integral techniques, such as manual pruning and the construction of dry-stone walls surrounding the trees. In terms of Apulian society and economy, particularly in Salento, the degradation of the landscape, characterised by centuries-old olive trees, threatens tourism, thereby jeopardising both the local economy and the region's cultural heritage. Additionally, the subsequent economic decline may drive residents to migrate to more prosperous areas, further destabilising the local community. Moreover, Apulia's tourism has historically thrived on olive cultivation, as traditional Apulian cuisine

heavily relies on extra virgin olive oil, supported by tours of ancient oil mills and other recreational activities.

In this line, financial and technical support measures are essential for aiding farmers affected by Xfp in transitioning their crops or adopting alternative agricultural practices. These findings can serve as crucial information for policymakers tasked with establishing a compensation budget for Apulian olive growers impacted by Xfp. The proposed policy could further endorse initiatives aimed at conserving and enhancing traditional agricultural and architectural techniques, such as manual pruning and the construction of dry-stone walls. These initiatives not only preserve local farming culture but also create opportunities for cultural tourism and environmental education.

In addition, it is vital to continue investing in research and scientific innovation to develop olive tree varieties that are resistant to Xfp and to promote ecofriendly control methods. Raising awareness among citizens, farmers and tourists about the importance of conserving olive groves and the Apulian landscape should also be a priority. Given that Xfp poses challenges that extend beyond regional boundaries, collaborative policies should increasingly focus on international cooperation to share knowledge, experiences and resources with other regions and countries facing similar issues. Such collaboration could yield more effective and comprehensive solutions to combat this threat. Moreover, decision-makers should continue to invest in intensive monitoring and control programmes for Xfp to continuously control and prevent its spread and protect remaining olive groves in the studied region. This highlights the importance of adopting effective measures such as regular inspections, quarantine measures and financial support for research on biological and environmentally friendly control methods.

Ultimately, the pressing need for coordinated action to address the socio-economic and cultural impacts of Xfp in Apulia cannot be overstated. By fostering resilience through innovative agricultural practices and community engagement, we can work towards mitigating the devastating effects of this crisis and securing a sustainable future for both the olive-growing sector and the region as a whole.

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### Conflicts of Interest

The authors declare no conflicts of interest.

### Data Availability Statement

The data are available from the corresponding author upon reasonable request.

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