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Land Suitability Analysis of Six Fruit Tree Species Immune/Resistant to *Xylella fastidiosa* as Alternative Crops in Infected Olive-Growing Areas

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Abstract: Olive agro-ecosystems in southern Italy have been heavily damaged due to *Xylella fastidiosa* subsp. *pauca* (Xfp). Replacing the Xfp-infected olive-growing areas with economically viable fruit tree species is thought to be a practical control measure. A land suitability analysis can provide an appropriate evaluation of a crop's suitability in these areas. We evaluate the suitability of almond (*Prunus dulcis* B.), fig (*Ficus carica* L.), hazelnut (*Corylus avellana* L.), kiwifruit (*Actinidia chinensis* P.), pistachio (*Pistacia vera* L.), and pomegranate (*Punica granatum* L.) as fruit tree species immune/resistant to Xfp to be planted within the Xfp-infected olive-growing areas in the Apulia region to compensate for economic and environmental losses. Climate and soil data were used to carry out the land suitability analysis. We combined information for each parameter to obtain the overall suitability maps for the six proposed fruit tree crops using GIS (Geographic Information System). The analysis showed that the Xfp-infected olive-growing areas are suitable for the plantation of most of the proposed fruit tree crops, with different suitability levels as the climate and soil conditions vary among the study areas. In particular, large olive-growing areas are suitable for the cultivation of pomegranate (268,886 ha), fig (103,975 ha), and almond (70,537 ha), followed by kiwifruit (43,018 ha) and pistachio (40,583 ha). Hazelnut, with just 2744 ha of suitable land, was the species with fewer suitable areas in these semi-arid environments. This is the first study to provide practical containment measures against the diffusion of Xfp in southern Italy. Our results can help in the selection of the right immune/resistant tree species for replanting in Xfp-infected zones, therefore providing guidelines within the decision-making process to encourage the planting of some underrepresented fruit tree crops with viable economic values as well.

Keywords: drought stress; disease management; GIS; olive-infected areas

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1. Introduction

Olive trees represent symbols of historical, cultural, and economic importance in Italy as a whole and in the Apulia region particularly. According to the data published by ISMEA [1], the Apulia region produces 51% of the national amount of olive oil and hosts 19% of all Italian oil mills. However, since the discovery of *Xylella fastidiosa* subspecies *pauca* Sequence Type *53* (Xfp) in olive orchards and its outbreak in 2013 in Salento (SE of the Apulia region, Italy [40.892: 39.789 N, 16.695: 18.520 E]) [2], the Apulian area where olives are the dominant cultivation, the agro-ecosystems have been heavily damaged due to this olive quick decline syndrome (OQDS). The Xfp is a quarantine bacterium in the European Union (EU) and created unprecedented turmoil for the local economy, posing critical challenges for its management [3]. Despite the control measures adopted by the governance authority of Apulia (DGR 1999/2016 and DGR 1890/2018) to control its spread, Xfp is continuously expanding in the rest of the region, causing a significant impact on the environment, landscape, and, therefore, the economy [4] putting the regional economy at risk. In this regard, disease management guidelines should be drawn to provide the local farmers with the necessary knowledge and provide a sustainable alternative to the already compromised olive cultivation. These management guidelines should follow the strategy of "Replacement in Perennial Crops" for successful disease management [5]. In fact, planting new orchards with different tree species can represent an advantageous alternative to the traditional olive monoculture in the Apulia region, with potentially positive effects on the biodiversity [6]. Moreover, farms specializing in monoculture are more vulnerable than those where more species are cultivated, particularly with the intensification of the competitive pressure [7]. Agricultural diversification through the transition from the exclusive and repeated cultivation over time of a single tree crop in a certain area towards the introduction of several different tree species that are formerly underutilized or neglected can represent a practical option in suppressing pest outbreaks, preserving biodiversity, and optimizing water management when facing water scarcity problems [8]. Several studies have shown that some tree crops, such as almond and pomegranate, may represent significant sources of health-promoting substances that are considered fundamental to a healthy diet [9,10], improving the ecosystem quality, farm income, and employment opportunities [11–13].

Several reports indicate that olive cultivated areas in southern Italy, especially in Apulia, are at greater risk and could be completely destroyed [14]. Therefore, in order to maintain the sustainability of the Apulian agro-ecosystems and to minimize the risks, there is a need for the evaluation of the suitability of a number of fruit tree species in order to replace olive orchards damaged due to Xfp-infection [15]. Current challenges, such as climate change adaptation, the spread of new pathogens, the loss of resilience, and water restrictions, require producers to invest in crops that can overcome these challenges [16].

Land suitability analysis (LSA) is believed to be an important step in land-use planning [17]. It facilitates identifying and formulating effective agricultural management strategies required for smart agriculture [18], thanks to their significant new capabilities in the use of spatial or geospatial information [19]. A land suitability appraisal is the evaluation and aggregation of the suitability of particular areas of land for defined uses [20]. As recommended by the Food and Agricultural Organization [21], LSA involves qualitative valuations of topography, vegetation, climate, hydrology, and soil properties, which typically are performed separately for each crop type [22]. He et al. [23] indicated that the land suitability evaluation for tree crops is very significant for agricultural production in the ecologically vulnerable regions of semi-arid zones.

In this study, we provide first insights on the potential replacement of infected olive orchards with immune or resistant fruit trees, which can be a practical option to manage the widespread of Xfp in other orchards or nearby areas. However, the implementation of this management strategy should emphasize the application of correct methodologies to evaluate the new alternative fruit tree crops and identify the areas, within Apulian olive orchards, where new orchards can be planted. Therefore, the aim of this study was to analyze the land suitability of six alternative fruit tree crops immune or resistant to Xfp within areas affected in the Apulia region, providing farmers with an agronomic and economic sustainable alternative solution in order to offset the already compromised olive cultivation environments.

2. Materials and Methods

2.1. Study Area

The investigated areas are within the borders of the Apulia region (southern Italy), (Figure 1A). In this region, agriculture plays a prominent economic role [24]. Apulia is the land of olive trees, which characterize the landscape and the economy. It is first on the national level in terms of both area and production [25]. In this study, we considered the regional areas where Xfp was first discovered; therefore, most olive orchards are believed to be affected by the widespread OQDS disease. In particular, we considered the olive-growing areas within three provinces (Lecce, Brindisi, and Taranto) where OQDS is mostly spread. In addition, we considered the buffer zone areas (Figure 2) where preventive measures against the advances of the disease are mandatory (Figure 1B). Foggia was the only province from the Apulia region that was excluded from this study because it is out of the infected area.

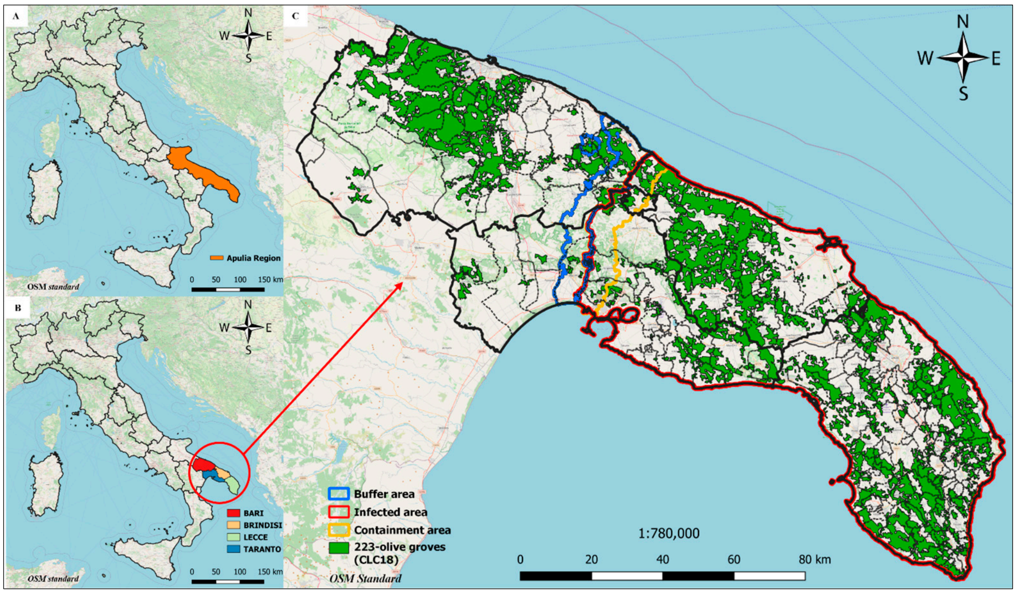

Figure 1. (**A**) Apulia region; (**B**) location of the four study provinces; and (**C**) distribution of olive orchards showing Xfp-infected areas (red border), areas under monitoring and the application of containment measures (yellow border), and the blue border indicates the buffer zone areas (Source: Territorial System (SIT Puglia) database).

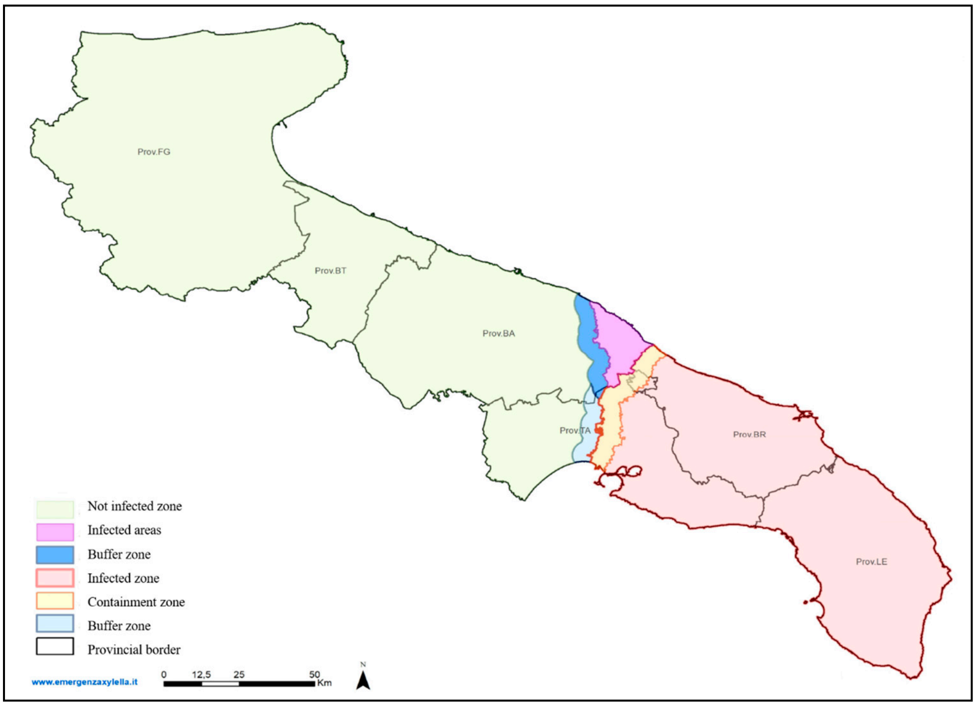

Figure 2. Updated situation of Xfp-infected zones (determination of the plant health observatory section manager 17 November 2022, n. 127 Xylella fastidiosa subspecies pauca ST53—update of the areas delimited, pursuant to art. 4 of Reg. UE 2020/1201 (*Bollettino Ufficiale della Regione Puglia* [26])).

2.1.1. The Establishment of the Base Maps

The territorial analysis started with the establishment of the base map (Figure 1C) showing the spread of olive orchards where most of the orchards are infected by Xfp. Data on the olive-production sites in southern Italy were obtained from the CORINE land-cover map 2018 W.2020 (https://land.copernicus.eu/pan-european/corine-land-cover (accessed on 14 May 2021) and the data on the last update of the regional areas infected by Xfp were provided by the governance authority of the Apulia region (Figure 2) [26]. The administrative limitations (in terms of the single municipality) of the study areas were defined using the shapefiles of the Apulian municipalities and the provinces reported in the Regional Territorial Landscape Plan (PPTR) updated on 20 December 2020. Figure 1C shows the Xfp-infected areas, particularly the areas of Taranto, Brindisi, and Lecce municipalities (with the red border). In addition, we also took into consideration the municipality of Bari (Figure 1C, divided for the rest of the infected areas by the buffer zone (blue border, considered equal it because followed the same regional rules)) for the potential advancement of the infection [14]. All the considered areas (Figure 1C) underwent the land suitability analysis.

2.1.2. Actual Land Use of the Study Areas

Data on the different categories of land use in the study areas were obtained from the CORINE land cover map (https://land.copernicus.eu/pan-european/corine-land-cover; accessed on 14 May 2021), excluding natural parks, Natura 2000 network areas, forests, and urban areas (Figure 3). The analysis of the land use data shown in Figure 3 indicates that 36% of the study areas were devoted to olive orchards (green areas), with respect to the total cultivated areas. Vineyards represented about 9% whereas other fruit tree crops occupied only 2% of the total. Almost 70% of the olive orchards were located in the Xfp-infected areas of the three municipalities (Lecce, Brindisi and Taranto), with 213,893 ha of the total olive-growing areas. Bari province accounted for the 'remaining' 104,165 ha (32.8%). The largest olive orchard areas were located in the municipality of Lecce (105,768 ha) which represented about 33.3% of the total olive orchards of the study area, followed by Brindisi (24.5%) and Taranto (9.5%), with an area of 77,960 ha and 30,165 ha, respectively.

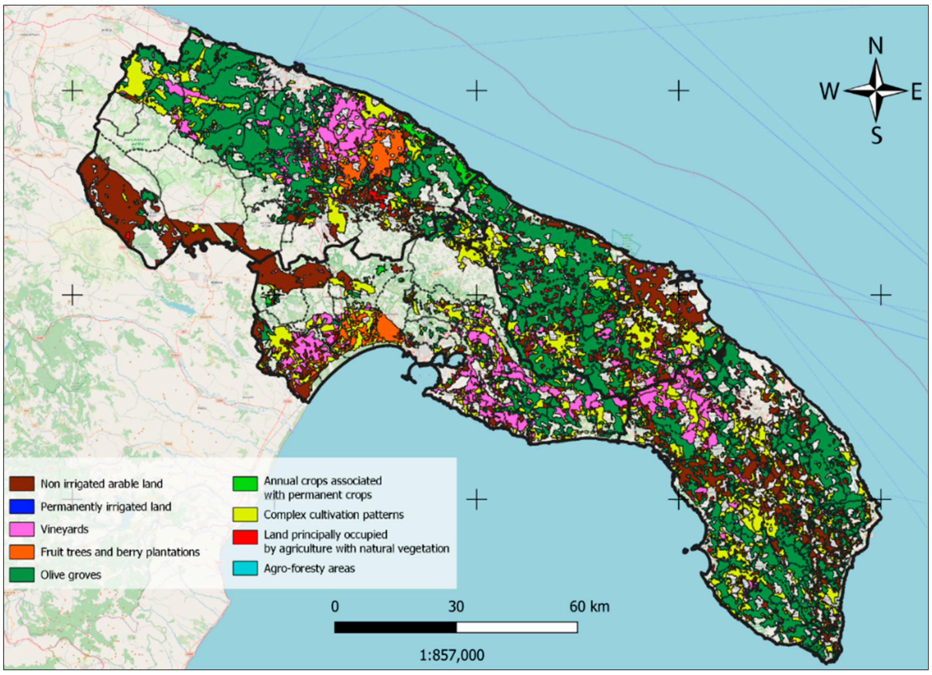

Figure 3. Land use of the areas under study (Apulia region, SE Italy) from CORINE land cover [CLC18v20] (https://land.copernicus.eu/pan-european/corine-land-cover; accessed on 14 May 2021).

2.2. Alternative Fruit Tree Crops Selection

This study evaluated the possibility of cultivating six fruit tree species throughout the Xfp-delimitated areas: almond (Rosaceae: *Prunus dulcis* B.), fig (Moraceae: *Ficus carica* L.), hazelnut (Betulaceae: *Corylus avellana* L.), kiwifruit (Actinidiaceae: *Actinidia chinensis* P.), pistachio (Anacardiaceae: *Pistacia vera* L.), and pomegranate (Lythraceae: *Punica granatum* L.). The hierarchical selection criteria of the fruit tree species were based firstly (i) on immunity/resistance to Xfp, then (ii) on economic importance, and finally (iii) on drought stress resistance suitability.

Following the first-mentioned criterion, fig, hazelnut, kiwifruit, and pomegranate are Xfp-immune species [27]. In the case of almond, even if it is reported as Xfp-susceptible specie [2], the Apulian authority classified it as resistant specie (host specie with minor infection symptoms) [28], so this has allowed the implantation as an alternative crop in the infected olive orchard areas (Determination of the Phytosanitary Service of the Apulia Region n. 75, 3 August 2021). Finally, for pistachio, which is formally Xfp-susceptible as almond, no infected nor symptomatic trees were reported in the infected areas [27].

Regarding the second criterion, almond and pomegranate cultivations should generate in the same areas interesting performances, both in terms of environmental load and economic profitability [8]. Moreover, several studies demonstrated the health properties of these fruits [10,29], which is reflected in the increase in demand and the average market price. The selling price of pistachio is currently about 12 EUR/kg [30] due to the nutritional value of dried nuts [31]. Recently, there has been an increased interest in the commercial production of pomegranate, and the fruit is being consumed not only as fresh fruit but also as juice or as a freshly prepared product [32]. The kiwifruit has an economic and interesting value [33], in that the interest of fruit growers is increasing in southern Italy [34]. Moreover, almond and fig are already part of the Apulian agricultural biodiversity [35]. The authors indicated that almond cultivation, for example, has great traditional and economic relevance in southern Italy, especially in the Apulia region, accounting for 96% of the national production.

For the third selection criterion, most of the selected fruit tree crops have a range of morphological and physiological adaptations that allow them to survive water-stress conditions, including almond [36], pistachio [37,38], fig [39], and pomegranate [32]. Kiwifruit showed some adaptation abilities to drought [40], whereas hazelnut showed some sensitivity to drought [41]. The adoption of drought-tolerant crops, integrated into well-established strategies for saving water in agriculture (e.g., regulated deficit irrigation, drip irrigation systems, etc.), may contribute to improving biodiversity, facing problems of water scarcity, and making the agroecosystems more resilient [8].

2.3. Parameters Used in the Land Suitability Analysis

The studies conducted on the land suitability evaluation of a crop in a specific area have been based on climatic and soil-site databases [42–45]; in particular one climate (chilling requirements) and three soil key-parameters (texture, pH, and salinity) were considered in this study to create suitability maps, with reference to those reported in the literature as optimum values for the crop growth of the six fruit tree species (Table 1). The soil database was obtained from the ACLA 2 project, focused on the agro-ecological characterization of the Apulia region by means of potential productivity [46].

Table 1. Climate and soil requirements for the selected fruit tree species growing (values may vary among cultivars).

Fruit Tree Crop	Chilling Requirement (h)	Soil Texture *	Soil pH	Soil Salinity (ECe; dS/m)	References
Almond	350–500	S, SC, CL	5.5–8.5	<2.0	[47,48]
Fig	300–500	wide range of soils (S, SCL, LS, L, C)	6.0–6.8	<4.2	[49]
Hazelnut	>600	L, SCL, CL, SC	6.0–7.0	<2.0	[50,51]
Kiwifruit	700–1000	C, CL	5.5–7.0	<0.4	[52]
Pistachio	600–1000	SC	6.5–7.5	<6.0–8.0	[53,54]
Pomegranate	230–630	All type of soils	6.5–7.5	<6.0	[55–57]

* C = clay; SC = sandy-clay; L = loamy; CL = clay-loam; SCL = sandy-clay-loam; S = sandy; LS = loamy-sand.

2.3.1. Climate Suitability

To assess the climate suitability, climatic data of the Apulia region went under processing, interpolating, and mapping within the study areas. Climatic data related to the key climate variable (hourly temperature data) have been obtained from 62 meteorological stations distributed throughout the region (Figure 4) and provided by the regional agro-meteorological service (ARIF). Data from the 62 thermo-pluviometric stations were used considering a period from 1994 to 2020 (Figure 4).

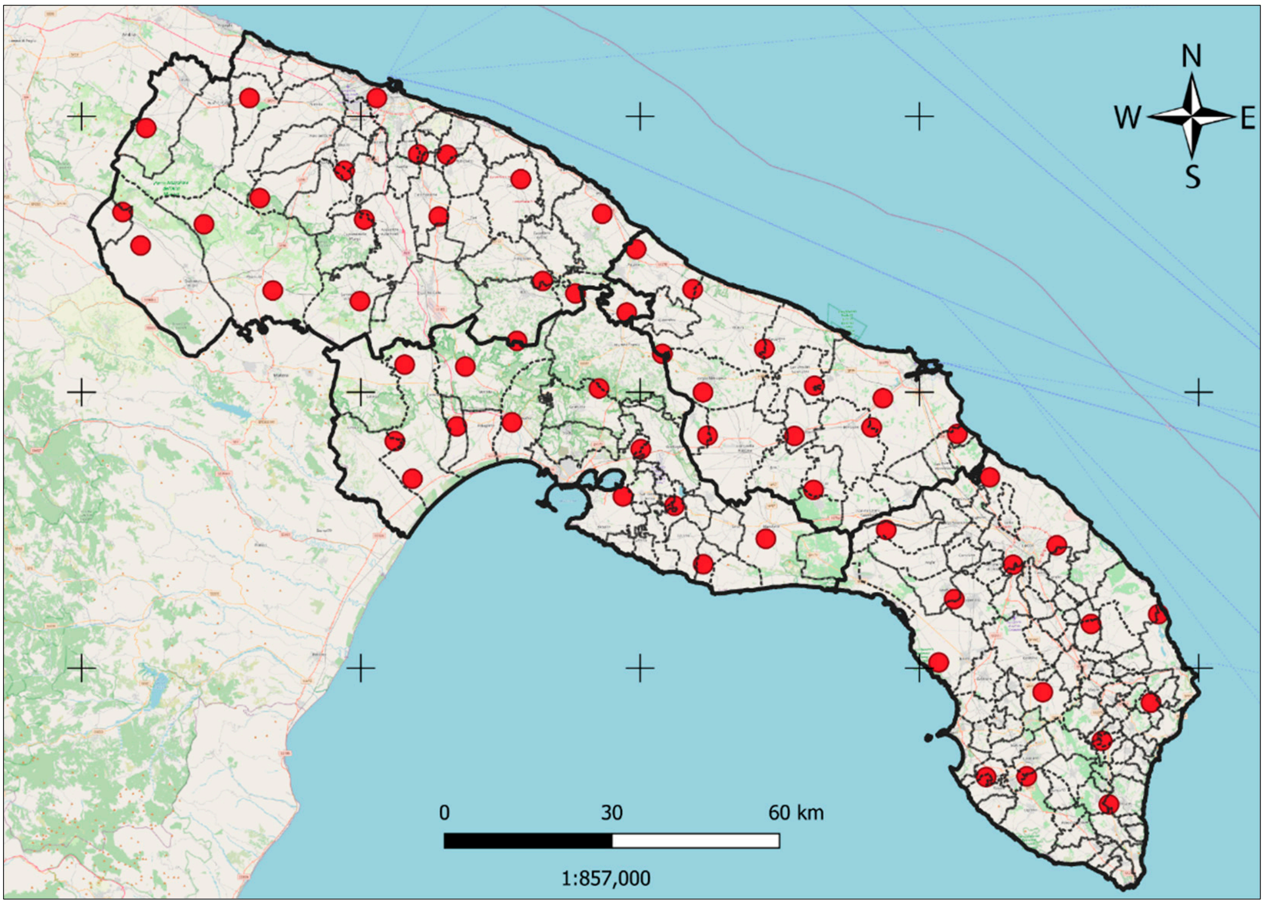

Figure 4. Localization of the meteorological stations (regional agrometeorological service—ARIF Puglia) considered for the climate data collection.

The analysis included the identification of some ecological optimum conditions such as chilling hours for the investigated areas of the region. Due to the fact that the knowledge of the chilling requirements for breaking rest and flowering of fruit trees is necessary to properly select cultivars and to avoid losses due to an inappropriate cultivar selection in a particular geographical location [58], we used 1994–2020 climate data to estimate the accumulation of chilling hours by each station, quantifying its spatial variability and representing the spatial pattern throughout the Apulia region (Figure 5). The chilling offer by each station (Figure 5) was calculated by using the Weinberger method in RStudio [59] by counting the number of hours (1 October to 15 February) with an hourly temperature between 0 and + 7 °C, considering that in the literature chilling requirements are still available as chilling hours for most of the selected fruit tree species [47–57] and, in order to obtain the map, ordinary kriging (OK) was used. In the map (Figure 5), the level curve referred to the variance has also been included in order to define and show the error made by the model used for the interpolation. The areas in which the model has made the greatest estimation errors are those in which the variance value is greater than the others. In these areas, the estimated chilling hours should not be considered as an actual value, but it is important to consider the error made by the model.

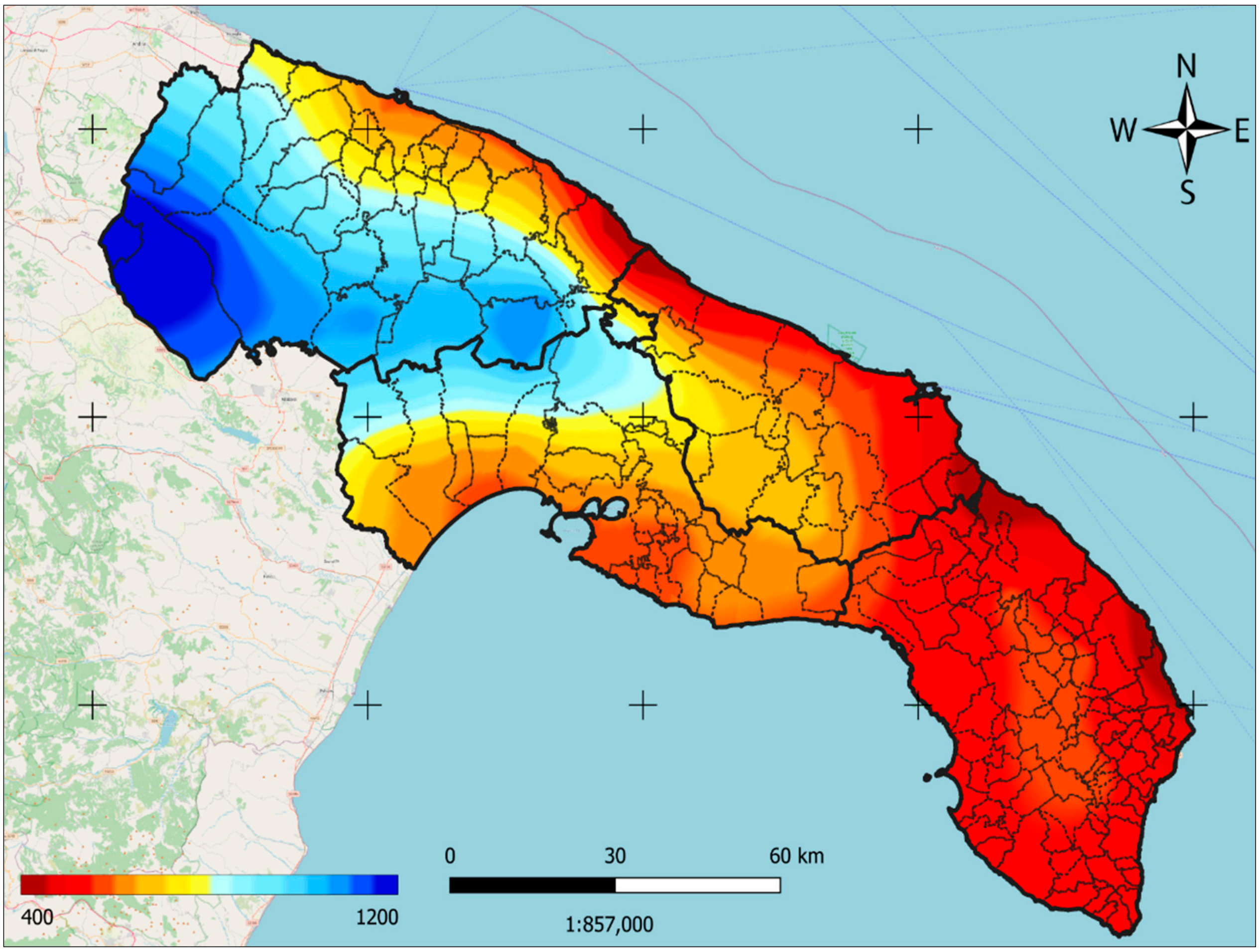

Figure 5. Number of chilling hours, as mean of 26 years (1994–2020; regional agrometeorological service—ARIF Puglia).

2.3.2. Soil Suitability

The regional soil database was obtained from the regional project (ACLA 2; Agroecological characterization of the Apulia region as a function of production potential). In particular, the following soil data information layers were extrapolated as shapefiles: pH, soil texture (USDA classification), and soil salinity (ECe; dS/m). Figure 6 shows maps of important soil parameters such as (A) soil pH, (B) soil salinity, and (C) soil texture across the investigated areas.

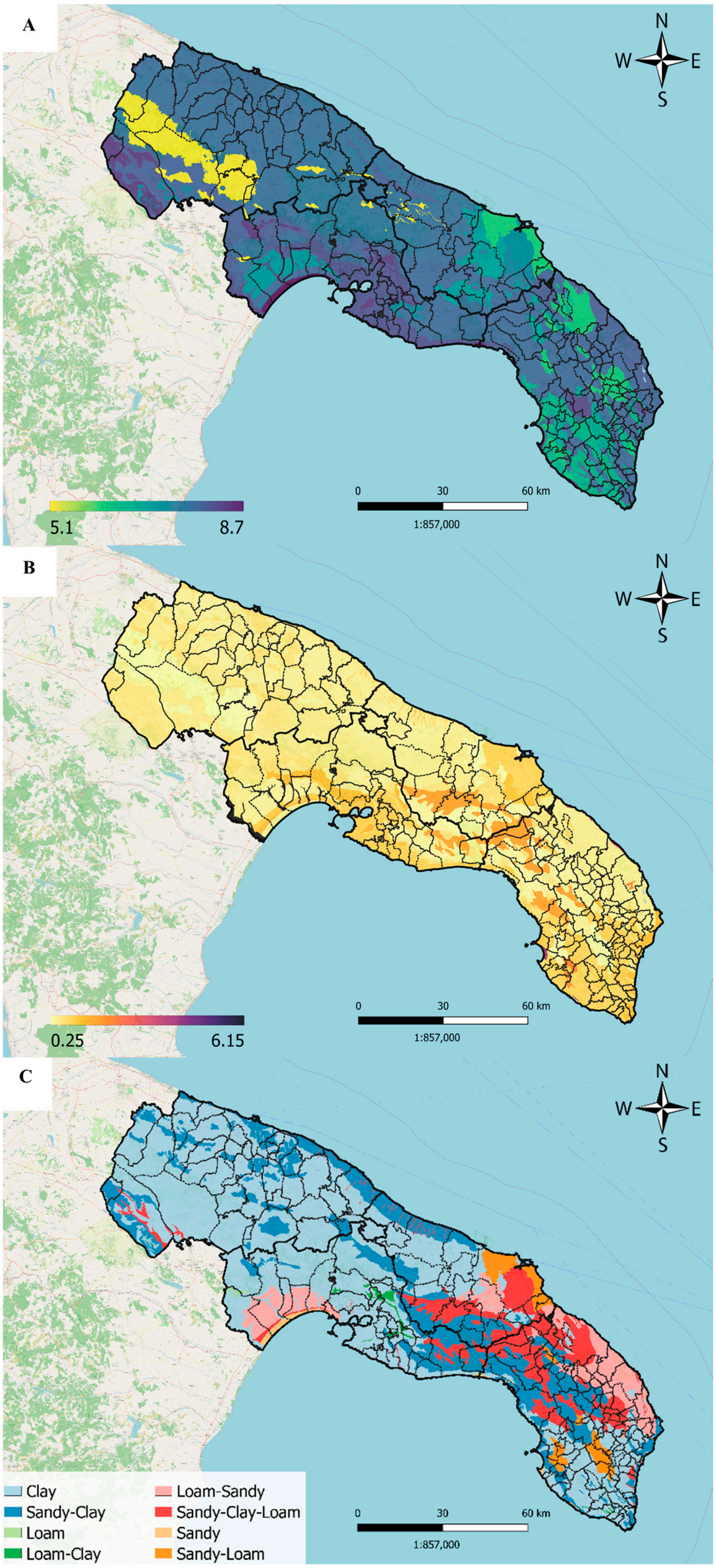

Figure 6. Mapping of important soil parameters showing (**A**) soil pH; (**B**) soil salinity (ECe; dS/m); and (**C**) soil texture along the investigated areas of the Apulia region (ACLA2 database).

2.4. Spatial Analysis and Land Suitability Map Generation

The use of GIS in land suitability studies contributes to the overlay analysis, to the creation of distribution maps, and to the suitability classifications [60]. Leisz et al. [61] stated that GIS-based analyses are very useful in land suitability analysis. In this study, cartographic and geospatial processing were carried out with QGIS 3.22.11 software using WGS 1984 UTM/ZONE 33N (EPGS: 32633) as the coordinate reference system (CRS) to perform the spatial analysis and to generate climate and soil suitability maps with reference to the same period mentioned in the Section 2.3.1 (climate data 1994–2020).

By the time the maps were obtained for each parameter, it was necessary to combine all the information to obtain the overall suitability map. For each parameter used in the land suitability analysis for each crop, binary datasets were produced through a raster layer in which the cells were assigned a score in the 0–1 range expressing its degree of suitability (0 = not suitable and 1 = suitable) in order to generate the final suitability map. After the individual raster layers had been obtained, a merge operation was carried out to obtain a final raster (in this layer, the cells with value 1 represented the areas in which all the conditions taken into consideration had been satisfied). Based on the information provided, suitability maps for the six fruit tree species were built covering the whole study areas. The final maps of the six fruit tree crops suitability zones were modeled by overlaying different spatial layers and considering their influence coefficient, based on the weighted overlay method in the GIS environment. This approach, while easy to implement, includes one of the common algorithms used in spatial analysis in GIS [54]. This approach was previously used by other authors [60,62] and it was implemented in this study for the study provinces.

2.5. Data Analysis

Climatic data processing and analysis were carried out using RStudio (RStudio, PBC, Boston, MA) for Windows, Version 1.3.1093.0. The elaboration of climate data in RStudio was conducted in order to obtain the dataset used in QGIS. Subsequently, the data were interpolated using ordinary Kriging statistical techniques to create a map showing the spatial variability of chilling hours in the study areas.

3. Results and Discussion

3.1. Suitable Areas

Site selection was carried out in the area under study considering only the olive-growing areas to identify the suitability of infected orchards for the cultivation of the selected fruit tree crops. Table 2 shows the surfaces (in hectare) of the olive-growing areas that had been identified as suitable for the cultivation of each tree crop.

Table 2. Suitable areas (ha) of the selected fruit tree crops in Xfp-infected olive-growing areas.

Fruit Tree Crop	Total Area (ha)	Area by Province (ha)			
		Bari	Taranto	Brindisi	Lecce
Almond	70,537	12,596	14,143	25,737	18,061
Fig	103,975	12,503	15,239	35,503	40,730
Hazelnut	2744	0	460	2227	57
Kiwifruit	43,018	42,303	382	333	0
Pomegranate	268,886	88,958	22,037	71,135	86,756
Pistachio	40,583	82	1768	7902	30,831

The highest percentage (85%) of olive orchards of the study areas suitable for the cultivation of pomegranate with a total surface of 268,886 hectares were mostly located in the province of Bari (88,958 ha; 33.1%), followed by Lecce (86,756 ha; 32.3%) and Brindisi (71,135 ha; 26.5%). Taranto showed the least suitable area of pomegranate cultivation, with a total suitable area of 22,037 ha representing only 8.2% of the olive orchards located in the study areas (Table 2). These data are supported by the wide spread of this fruit tree crop cultivation in the region; indeed, Apulia is one of the most important Italian regions for pomegranate cultivation, supplying about 34% of the national production, according to ISTAT [63].

Fig cultivation, with a suitable surface of 103,975 ha, was the second tree crop suitable, with about 33% of the total olive-growing areas, representing a promising alternative drought-resistant fruit tree crop in the Xfp-infected areas. As there has been a progressing decline in fig cultivation in Italy, particularly in Apulia, in the past fifty years [64], our results can help extend the cultivation areas of fig in the region which can help in implementing the regional biodiversity enhancement plan. Table 2 shows that Lecce province had the highest suitable land for fig cultivation, with 40,730 ha (about the 39% of the total olive orchard areas of the region), followed by Brindisi with 35,503 ha (34.1%). The provinces of Bari and Taranto showed fewer suitability conditions for fig cultivation, with only 12 and 14.7% of the total areas cultivated by olive orchards, respectively.

Almond and pistachio showed good suitability for their cultivation in the olive-growing areas, representing part of the Apulian agricultural biodiversity enhancement plan as well. Almond appeared to have the third largest surface area suitable for their cultivation, with 70,573 ha representing 22% of the areas cultivated with olives (Table 2). Brindisi showed the highest suitable area for almond cultivation (36.5%), followed by Lecce (25.6%) and Taranto (20.1%), whereas Bari showed the lowest suitable areas for almond cultivation with only 17.9% (82 ha). Pistachio, on the other hand, showed interesting suitable areas with a total surface of 40,583 ha, corresponding to about 13% of the total areas, concentrated mainly in the province of Lecce (76%) and, to a lesser extent, Brindisi (19.5%). The province of Taranto showed only 4.4% of the investigated area is suitable for pistachio cultivation, while the province of Bari showed almost no suitability for pistachio cultivation (0.2%). According to FAOSTAT, the national production of pistachio in Italy is negligible with respect to the world production [65]; however, these results can help in increasing the national pistachio production, considering its phreatophytic behavior and extensive root system which allow the tree to survive long periods of drought under rainfed conditions in arid and semi-arid lands [66,67].

Suitability analysis data showed that 14% of the olive growing areas can be cultivated with kiwifruit (T_{opt}: 16 °C), representing 43,017 ha, similar to pistachio, but mainly concentrated in the province of Bari (98%), located mainly in the south-east part of the province (Table 2). The provinces of Taranto and Brindisi showed very low suitability for kiwifruit cultivation, with only 0.9% and 0.8%, respectively, while the province of Lecce showed no suitable land for the crop production. The analysis of the results suggests that several conditions have limited the land suitability for the cultivation of kiwifruit plants across the regional territory, including the high chilling requirement (Figure 5) and low soil pH (Figure 6A). However, in this study, the most limited factor for kiwifruit cultivation in the Apulia region is soil salinity (Table 1).

Finally, for hazelnut, this land suitability analysis did not give promising results, with only 2744 ha, representing 1% of the olive-growing areas. The suitable areas for hazelnut cultivation are concentrated mainly in the Ionian areas and in the territory between the provinces of Taranto and Brindisi (81.2% within Brindisi and 16.8% within Taranto). The province of Lecce showed very low suitability areas for hazelnut cultivation, with only 57 ha (2.1%), while the agricultural land of Bari appeared to not be suitable for hazelnut cultivation. Similar to kiwifruit, the most limiting factor for hazelnut cultivation in SE Apulia is the chilling requirement; therefore, planting cultivars with lower cold requirements could guarantee greater success for this crop in these environments.

3.2. Land Suitability Maps

Land suitability mapping, based on geographical information systems (GIS), is one of the most useful applications for spatial planning and management [68]. The suitability maps of the cultivation zones of six fruit tree crops, spatially modeled in GIS environment based on long-term meteorological data, are shown in Figure 7.

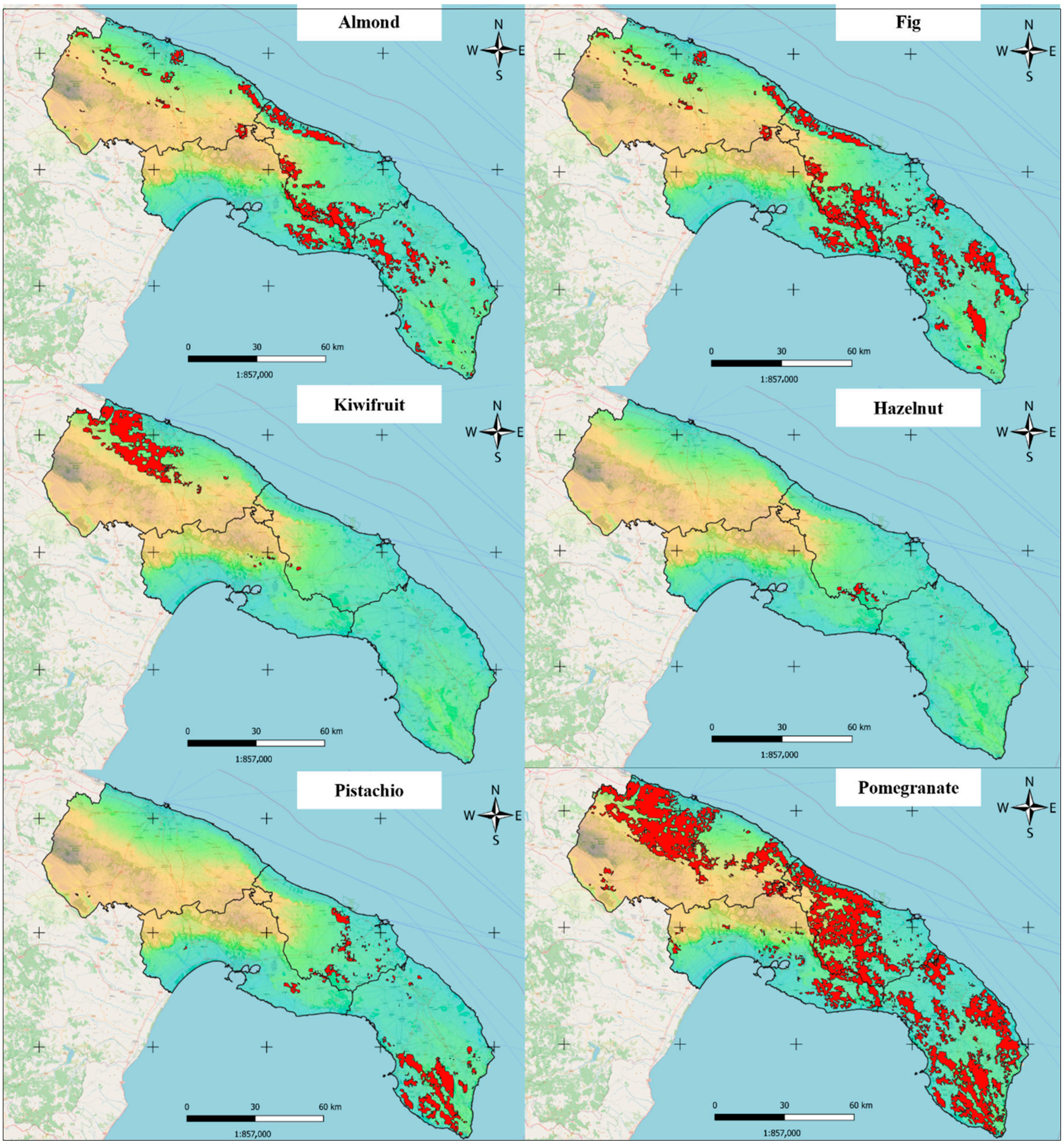

Figure 7. Land suitability maps of the six fruit tree crops within olive-growing Xfp-infected areas. Red zones indicate suitability areas for each species derived from a match between climate and soil data.

The figure shows the suitable olive orchard land areas (in red) that have the optimum climate and soil conditions, according to the information regarding plant requirements (Table 1), which are fundamental for the cultivation of each one of the selected fruit tree crops. As a whole, the land suitability analysis showed promising suitability results for most of the proposed fruit tree species, which can play important roles in enhancing the regional landscape biodiversity. Strobl [6] indicated that the possibility of planting new orchards with different tree species represents an advantageous alternative to the traditional olive monoculture, with potentially positive effects on biodiversity.

The distribution of the suitability zones for the six fruit tree species in the study area was indicative of a spatial matching suitable for the scattering of the climate and soil features and, consequently, the micro-climatic conditions of these areas, in line with Yarahmadi and Amini [54]. The land suitability map confirmed that most of the olive-growing Xfp-infected areas are suitable for pomegranate cultivation, followed by fig and almond (Table 2). This might be mainly due to the fact that three species have the ability to be grown in the different types of soils spread throughout the regional land, and these species can survive in high temperatures and drought conditions, as was highlighted by Ferrara et al. [69] in the case of pomegranate cultivation. As the Apulia region is considered to be one of the most important agricultural areas of the country, supplying about 96% of the national production of almonds [35] and 34% of the national production pomegranates [63], the land suitability analysis gave a promising result in terms of the potential cultivation of these fruit tree crops in a large area within the region and recovery from its declined production in the past decades with considerable economic consequences on the national market and regional economy [49,70].

Climate and soil conditions appear to be suitable for the cultivation of kiwifruit only in the province of Bari, whereas the other provinces (Brindisi, Taranto, and Lecce) showed little or no suitability for kiwifruit cultivation due to climate constraints, particularly chilling requirements. In fact, data on the number of chilling hours reported in Figure 5 showed that the province of Bari is the only regional area where kiwifruit can get the required winter chilling requirements (Table 1) necessary for plant development and fruit setting, compared to the other fruit tree crops. Although it is widely accepted that kiwifruit vines require chilling during winter to ensure the production of an adequate number of flowers [71], the timing and duration of winter chilling can affect the behavior of kiwifruit vines [72]. In their work, Snelgar et al. [72] found that a lack of winter chilling, i.e., warmer temperatures between May and August, reduces the kiwi productivity; therefore, adequate winter chilling results in a considerable period of budbreak, which can lead to more flower [73].

On the contrary, the land use suitability analysis showed that pistachio can be cultivated within the olive-growing areas of the drier provinces (Brindisi, Taranto, and Lecce), while the province of Bari was not suitable, mainly due to the relatively low temperatures compared to other provinces (Figure 5). Under the dry land conditions of Tunisia, Elloumi et al. [38] found that pistachio production appears to be more a function of annual chill accumulation than annual precipitation. The demand for pistachio nuts is pushing many countries to invest in the production of this fruit and in its cultivation [74]. Therefore, as about 90% of the total Italian pistachio area is concentrated in a few territories of eastern Sicily, mainly located in the province of Catania [74], these results can be used to extend the current cultivated land for pistachio in other Italian southern regions. Other factors believed to limit pistachio cultivation in the Apulia region might be related to soil characteristics. In fact, pistachio suitability map (Figure 7) falls within the areas with higher soil salinity and soil pH, compared with other areas (Figure 6A,B). A recent study by Zeinadini et al. [75] indicated that pistachio cultivation is compatible with unfavorable growth conditions, especially drought and salinity [54]. Following the same methodology used in this study, Everest [60] determined the suitable sites for pistachio cultivation by using basic soil properties, climatic data, geographical information system (GIS) and multi-criteria decision analyses. The author highlighted that the practice of land suitability analysis would contribute to the proper use of the land, and crop-based suitability would be very important for sustainable land use and to conserve the environment.

The land suitability map of hazelnut showed the crop had the lowest land suitability among the tested fruit tree crops (Figure 7). Only small areas, located in the border areas between the provinces of Brindisi and Taranto and, to a lesser extent, in the province of Lecce, were suitable for the cultivation of hazelnut, based on climate and soil characteristics. Dimitrijević and Bulatović [76] indicated that hazelnut varieties require special conditions of both climate and soil. Unlike water stress, which can be reduced with proper irrigation, Jha et al. [77] reported that an increase in the number of days with maximum temperature and/or minimum temperature could have negative effects and limit the growth of vegetative buds. According to the FAO [78], Italy is the second hazelnut-producing country (11.13%) after Turkey (70.74%), with an increase in the cultivation areas from 69,285 ha in 2016 to 80,280 ha in 2020 ha [79]. Actually, there is a noticeable discrepancy between the actual demands for hazelnut fruits and the current production situation in Italy. Therefore, considering that the estimated hazelnut production by hectare is about 2 t/ha, the suitability areas from our land analysis, even if it is relatively small, can contribute to a significant amount of the national hazelnut production.

4. Conclusions

According to the authors' knowledge, there is no study in the literature about the selection of suitable sites within Apulian olive Xfp-infected growing areas for the cultivation of different commercially viable fruit tree crops as control and preventive measures for the spread of Xfp. This deficiency inspired this study to provide a new contribution to the literature as preventive measures in order to slow the spread of Xfp in Apulian olive orchards. The land suitability analysis indicates that a large part of the olive growing areas could potentially be suitable for the plantation of alternative fruit tree crops with similar economic importance. In particular, pomegranate showed the highest land suitability to be planted in most parts of the Apulian olive orchards, followed by fig and almond, to a less extent. The results of this study confirmed that land suitability analysis could be used as an important management strategy tool to identify the suitability of certain crops in certain areas in order to maintain the long-term viability and productivity of agricultural lands. The results can be more refined by tailoring the land suitability analysis to specific olive orchards where Xfp has already done considerable damage. Nevertheless, the final results of this study can contribute to a more informed decision making (e.g., selection of prevention/control measures) by integrating these results into the regional decision-making processes, in order to manage and reduce the damage of olive orchards affected by Xfp, as it gives insight into finding suitable areas. Our results can help in minimizing the environmental and economic losses while maintaining biodiversity components of the landscapes at a reasonable level. Information from this study can create a rational background in ensuring sustainable food production systems, agricultural land use planning, strategic planning, and the management of the Xfp-infected areas, enhancing farmers income and increasing the resilience of an agro-ecosystem.

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