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Using and Creating Microclimates for Cork Oak Adaptation to Climate Change

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Abstract: In Mediterranean climate regions, climate change is increasing aridity and contributing to the mortality rate of *Quercus suber*, reducing the success of reforestation efforts. Using and creating microclimates is a recommended climate adaptation strategy that needs research. Our hypothesis is that planting *Q. suber* in north-facing slopes and water lines results in a higher survival rate than those that are planted in ridges and south-facing slopes. Secondly, our hypothesis is that existing shrubs (in this case, *Cistus ladanifer*) can be used to create microclimatic sheltering and increase the survival of *Q. suber* plantations. In experiment 1, we tested the survival of *Q. suber* plantations in four different topographic conditions. For that, 80 *Q. suber* plants were planted over four different topographic conditions, where soil probes were installed to monitor soil moisture and temperature. Two years after, the results show an increased survival rate in the north-facing slope and water line when compared to the ridge area ($p = 0.032$). In experiment 2, we tested if planting in the shade of rows of *C. ladanifer* increases the survival rate of *Q. suber* plantations. For that, 1200 *Q. suber* plants were planted; 600 in a Montado open area with no shade and 600 under the shade of rows of *C. ladanifer* shrubs. A total of 17 months after plantation, there was a significantly higher survival rate of the shaded plants ($p = 0.027$). We conclude that microclimates created by topography and shrubs can have a significant impact on the survival of *Q. suber* plantations and discuss the situations in which these can apply.

Keywords: land degradation; landscape restoration; agroforestry; *Quercus suber*; Montado; Dehesa; shrubs; topography; farm adaptation

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1. Introduction

In Mediterranean climate regions, land degradation is a reality that can lead to desertification and poverty [1]. Under the climate scenarios RCP 4.5 and 8.5, aridity is projected to increase due to rising temperatures, more intense, longer and more frequent droughts and reduced precipitation [2,3]. As a consequence, susceptibility to land degradation in semi-arid regions is expected to increase, generating increased vulnerability to ecosystems [4], farmers and society [5–7]. In Portugal and Spain, Montado and Dehesa agro-silvo-pastoral systems [8] are pointed to as a solution for desertification or land degradation and as a climate adaptation strategy to increase resilience against climate change impacts [8–10]. However, these systems are facing the same threat of progressive degradation, namely an increasing mortality rate of the tree keystone species of these systems, *Quercus suber* L. and *Quercus ilex rotundifolia* Lam. [11,12]. Several authors have shown that in Iberia Peninsula, Montados and Dehesas are very sensitive to climate change, and their spatial distribution is likely to change or reduce [13–15]. In areas with low productivity, close to the limits of the *Q. suber* and *Q. ilex* climate envelope, afforestation and reforestation should be supported with additional measures to increase tree survival [16–19].

Quercus suber is distributed in areas with precipitation ranging from 400 mm to 2400 mm [20,21], but according to several authors, it is reported to thrive and be economically viable only above 600–800 mm of annual precipitation [22,23]. Regarding temperature, despite some authors stating that it thrives only below 31 °C of maximum absolute temperatures [23], Ghouil et al. (2003) have shown that photosynthesis of *Q. suber* seedlings (from acorns collected in Northern Tunisia) was at its optimum at 25 °C and started to decrease significantly only above 35 °C. Ghouil et al. (2003) state that optimal and critical temperatures of photosynthetic activity depend on interspecies variability and genotype, but also climate, since acclimatization is significant for critical temperature. In the case of *Q. suber*, critical temperatures can range from 42 °C to 56 °C depending on the acclimatization process and soil water content [24]. In this study, the CO_2 assimilation rate was progressively reduced under drought, reaching a value of zero after five days with a value of 5% of soil water content. The works of Ghouil et al. (2013) and Vanhove et al. (2021) showed that *Q. suber* has high gene diversity and tolerance to high temperatures, resulting in a significant climate adaptive capacity.

Regardless of the abovementioned abilities, the regeneration of cork oak stands faces serious difficulties, caused by a combination of factors such as drought, heat, over-grazing, pests and diseases. Extreme heat and drought generate stress on plants, saplings and seedlings, which leads to reduced productivity and damage with no short-term recovery prospects [24], eventually leading to mortality [25–30]. The same pattern happens in the case of afforestation efforts of *Q. suber* and *Q. rotundifolia*, with these plants suffering from very high mortality rates and low survival in Mediterranean climate regions as a result of several factors such as genetic diversity, the climate (e.g., drought, water scarcity, very high temperatures), soil characteristics (e.g., water holding capacity, depth, lithology, texture, nutrients, pH), presence of root pathogens such as *Phythopthora cinammommi*, herbivory and wild animals, namely wild boars and ungulates [14,15,26,30–32].

Using and creating microclimates has been identified as the main adaptation strategy to reduce exposure of vegetation to extreme climate variables, thus reducing the vulnerability to climate change [33]. Several authors have shown the impact of microclimate factors on the success of *Quercus* spp. afforestation efforts in the Mediterranean climate regions, namely potential solar radiation, shade, elevation and soil water content [34–38]. In the context of the Montado and Dehesa systems, Príncipe et al. (2014) showed increased long-term survival of *Q. rotundifolia* in north-northwest facing slopes in South Portugal.

Microclimates can be created by the presence of shrubs. Several authors have shown that shrubs can facilitate seedling and sapling survival by creating shade, reducing radiation and temperatures, increasing soil moisture and reducing water stress [38–41]. Skidmore and Hagen (1970) also showed that vegetation creates a windbreak effect, which reduces evaporation by 35% within a distance of four times the height of the windbreak [42]. In addition, neighboring shrubs can facilitate seedling and sapling survival by reducing soil compaction and adding organic matter [39,41,43]. In a meta-analysis developed by Gómez-Aparício et al. (2004), this effect was observed in high-stress areas where species are close to the limits of their climate envelope [39]. In areas where the abiotic environment does not limit the plants, the benefit from the proximity of shrubs was less evident in the Mediterranean late-successional trees and plants, tested in their study [39]. Mediterranean oak trees such as *Q. ilex*, *Q. faginea* and *Q. pyrenaica* were tested in these studies in combination with shrubs such as *Cistus albidus*, *Cistus mospeliensis*, *Ulex parviflorus* or *Genista hirsutae*. Results showed that shrubs have a facilitating effect on the survival and growth of the seedlings of *Quercus spp.* as well as on the germination and emergence of acorns [39,41]. Moreover, Plieninger et al. (2010) showed that tree regeneration of *Q. suber*, *Q. ilex* and *Q. pyrenaica* is positively correlated with tree cover and density as well as with the presence of pioneer shrubs.

Reforestation and forest management practices tend to eliminate shrubs because these are perceived as competitors for moisture and nutrients [39]. Some studies show that there is a competing effect and reduced growth of *Q. suber* due to the proximity of shrubs, namely *Cistus ladanifer*, and that forest management strategies should be evaluated carefully and with a site-specific approach [26,44]. While *C. ladanifer* can outcompete *Q. suber*, constituting a threat to the recovery of *Q. suber* ecosystems, the relation between *Q. suber* and *C. ladanifer* is highly dynamic and non-linear [45]. On the other hand, authors such as Arosa et al. (2015) or Simões et al. (2016) have shown that the survival rate of *Q. suber* germinations and seedlings increases in areas with plant cover, achieving the highest recruitment in areas with shrub patches covering 40–60% of the area [40,46].

This suggests that shrubs are beneficial and facilitate survival in the early stages of tree recruitment but compete when trees are already established, thus suggesting that shrubs should be included in the first stage and eliminated in the final stage of tree establishment. In fact, the results of Köbel et al. (2021) and Listopad et al. (2017), using the Montado system, show that tree regeneration increases in the first 5–10 years of grazing exclusion and growth of shrubs. On the other hand, tree regeneration decreases after this period, despite continuing to have a positive increase in the taxonomic diversity of shrubs until the 13th year [47,48]. Using shrubs as a tool for ecological restoration, afforestation and landscape regeneration, therefore, requires detailed analysis and design depending on the specific objectives.

Throughout the Mediterranean climate regions where land degradation is a reality, abandoned areas have been occupied by secondary shrub plant communities. One of the most frequent cases in the Iberia Peninsula is the shrubland plant community of Cisto-Lavanduletea Br.-Bl., which are dominated by Cistaceae (e.g., *C. ladanifer*.) and Labiatae (e.g., *Lavandula* Sect. *Stoechas*) [49,50]. *C. ladanifer* grows in very poor degraded soils, taking its niche after fires or plowing [50]. It occupies vast areas of abandoned or degraded Montado/Dehesas landscapes, increases fire risk and is considered a challenge for land restoration, also due to its allelopathic effect on some species [50].

Following this analysis, in this study, we have designed an experiment with *Q. suber* saplings planted in lines in the shade of rows of the main shrubs present in the Montado system, *C. ladanifer*, in an east-west orientation to increase the shade effect. Our hypothesis is that microclimatic conditions created by topography and shrubs will have a positive effect in the early stages of the survival rate of *Q. suber* plantation.

2. Materials and Methods

2.1. Study Area

The study area is located in the Iberian Peninsula, South Portugal region of Alentejo, municipality of Grândola, in the public farm of Herdade da Ribeira Abaixo (HRA). HRA is a 220 ha farm composed mostly of Montado, an agro-silvo-pastoral system with *Q. suber* as the main tree. This agroforestry ecosystem is classified, according to the European Forest Types, as a "9.1—Mediterranean evergreen oak forest" and "cork oak and holm oak forest" [51]. According to the European Nature Information System (EUNIS), this ecosystem is classified, depending on its configuration either as "T2112 Southwestern Iberian Quercus suber forests" or "R73 Mediterranean wooded pasture and meadow" and, more specifically, these habitats of conservation are Habitat "9330 Quercus suber forests" or "6310—Montados of evergreen Quercus spp", respectively.

This farm, which is a long-term socio-ecological site (LTsER), is mostly dedicated to education, research and conservation. The historical climate (1971–2000) in this area shows an average maximum daily temperature in August of 29.1 °C, an average temperature of 15.1 °C, a minimum average temperature in January of 5.7 °C, annual accumulated precipitation of 828 mm and an average of 78 days with rain per year. In the future climate scenarios, from 2070 to 2100, for RCP 4.5 and 8.5, respectively, the average temperature is projected to increase 1.7 °C and 3.4 °C, respectively. Under the same period and climate scenarios, the average maximum daily temperature in August is projected to have an anomaly of +2.2 °C and +4.0 °C, while the annual precipitation is projected to decrease by 68 mm and 179 mm [52,53]. In the years of study (2019, 2020 and 2021), the climate variables observed showed annual precipitation of 390 to 529 mm and average maximum temperatures in July and August above 31 °C (Tables 1 and 2).

Table 1. Values of temperature and rainfall for the case study area of Herdade da Ribeira Abaixo, Grândola, Portugal. Values with * are direct observations from the on-farm weather station. Values with ** are calculated based on adjusted interpolation of neighboring weather stations.

Variable/Year	1971–2000	2070–2100 (RCP8.5)	2019 **	2020 *	2021 *
Annual precipitation (mm)	828	649	404.8	529.0	390.2
Average temperature (°C)	15.1	18.5	17.0	16.8	17.4
Maximum temperature (°C)	-	-	38.9	40.8	42.4

Table 2. Monthly values of temperature and rainfall for the case study area of Herdade da Ribeira Abaixo, Grândola, Portugal. Values with * are direct observations from the on-farm weather station. Values with ** are calculated based on adjusted interpolation of neighboring weather stations.

	Precipitation (mm)					Average Maximum Temperature (°C)				
Month	**1971–2000**	**2070–2100 (RCP8.5)**	**2019 ****	**2020 ***	**2021 ***	**1971–2000**	**2070–2100 (RCP8.5)**	**2019 ****	**2020 ***	**2021 ***
January	-	-	43.7	35.8	53	-	-	16.7	16.1	16.9
February	-	-	35.1	10.8	93.2	-	-	18.4	20.1	16.8
March	-	-	14.4	33.4	19.6	-	-	21.3	20.1	20.3
April	-	-	82.0	90.8	62.6	-	-	20.6	21.3	22.7
May	-	-	8.0	52.2	13.2	-	-	28.0	27.7	26.5
June	-	-	5.4	2.4	10.2	-	-	26.7	28.4	28.9
July	-	-	2.8	1.0	1.6	-	-	29.1	36.0	32.1
August	-	-	18.8	2.6	2.4	29.1	33.1	30.9	32.0	32.5
September	-	-	5.8	11.2	26.2	-	-	28.5	30.1	25.9
October	-	-	19.1	101.8	32.6	-	-	23.3	24.0	23.7
November	-	-	112.6	93.0	19	-	-	17.5	19.8	16.9
December	-	-	94.5	94.2	56.6	-	-	16.7	15.5	15.8

2.2. Experimental Design

We designed two experiments with *Quercus suber* saplings to determine if microclimatic conditions created by topography and by shrubs can significantly improve the success of *Q. suber* plantations. In the first experiment, we planted *Q. suber* in four topographic conditions (i.e., different microclimatic conditions) to understand the impact on the survival rate of *Q. suber* saplings. In the second experiment, we planted *Q. suber* in lines between rows of *Cistus ladanifer* to understand if the rows of shrubs increased the success of *Q. suber* plantations.

The study area where experiments 1 and 2 were developed has a low density of trees (ca. 10 adult trees/ha), significant natural regeneration (>100 trees/ha) and was previously occupied by *C. ladanifer* shrubs (Figure 1). In both sites, the shrubs were shredded in December 2018 and again in October 2020 using a tractor with a shrub cutter with a chain. In experiment 2, Figure 1, the operations of shredding were performed leaving east-west oriented rows of *C. ladanifer* shrubs.

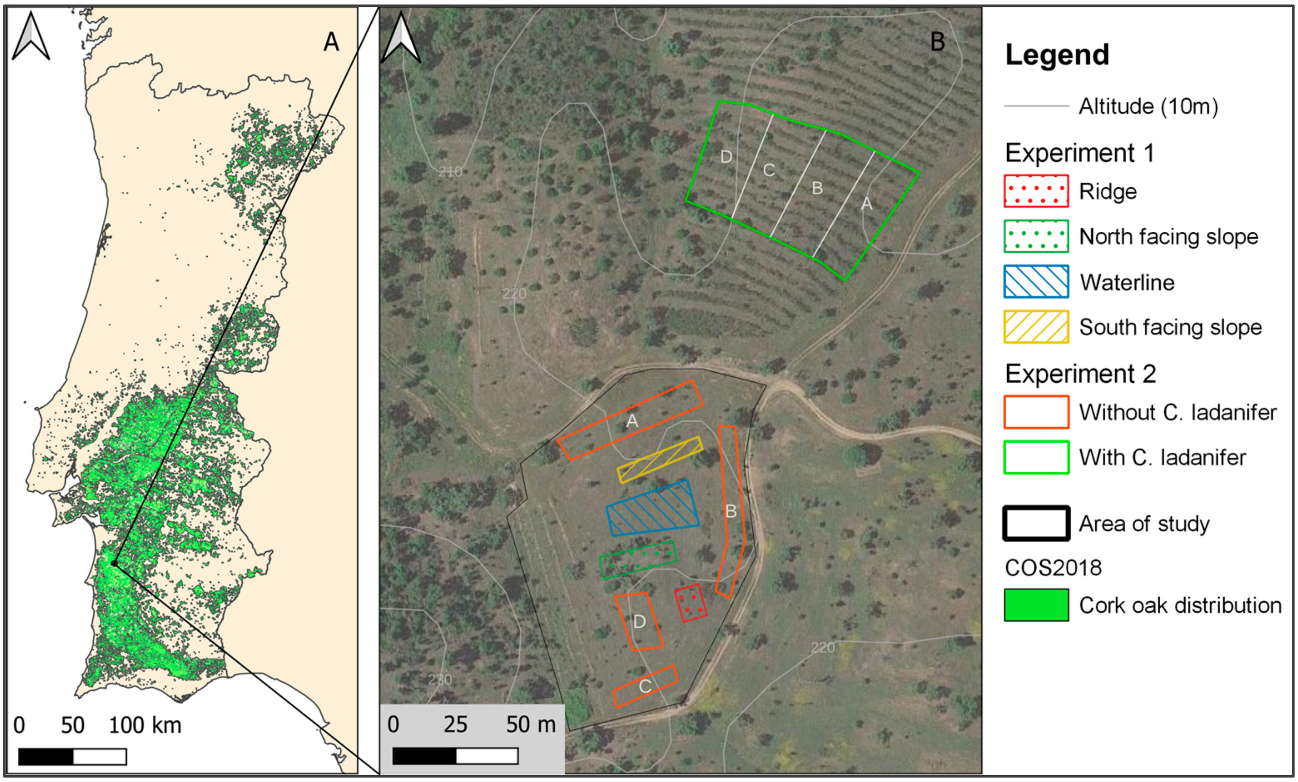


Figure 1. (**A**): Location of experiments on Herdade da Ribeira Abaixo farm located in the southwest of Portugal. In green, the distribution of Cork oak in Portugal is presented. Source: COS 2018 [54]. (**B**): Satellite view of location of experiments 1 and 2. Polygons marked with A,B,C,D are different replicate blocks inside each area of experiment 2.

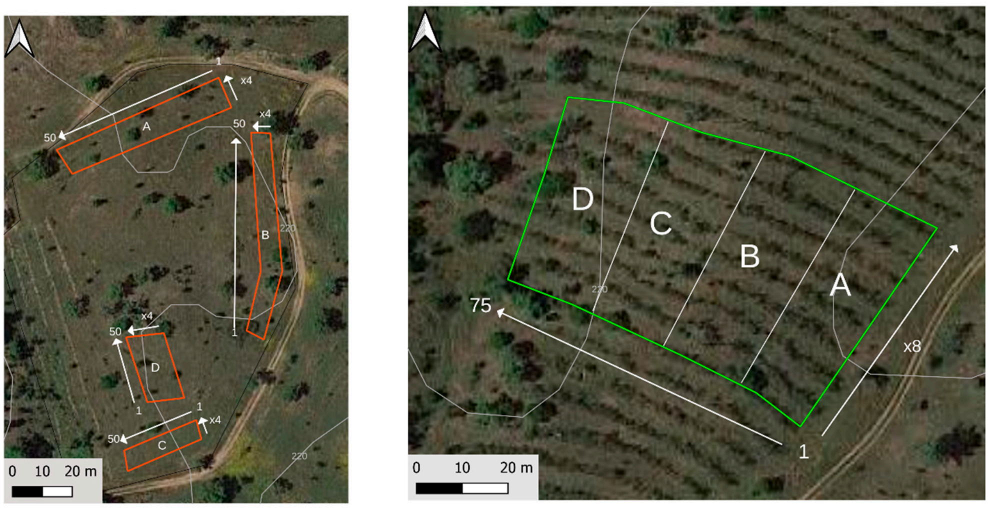
In experiment 1, we planted 80 *Q. suber* saplings, which were about one year old, divided across four neighboring areas with different topography, slopes and shade levels to confirm whether the microclimate has a significant effect on tree survival (Figure 1, Table 3). In each of the four sites, (A: south-facing slope, B: temporary water line, C: north-facing slope, D: ridge), 20 trees were planted with a minimum spacing of 1 m. The whole perimeter was fenced to protect against wild boars. The plantation was carried out in February 2019 and the last monitoring of survival and growth was carried out in March 2022 (Table 3).

Table 3. Synthesis of the experimental designs implemented in Herdade da Ribeira Abaixo, Grândola, Alentejo, Portugal.

	Samples of *Q. suber*	Experimental Design	Plantation	Final Monitoring
Experiment 1 topographic microclimate	80 saplings planted and monitored (0 damaged)	4 sites: north, south, water line, ridge. 4 blocks each.	17 February 2019	5 March 2022 (36 months)
Experiment 2 shrub rows microclimate	1200 saplings planted, 972 monitored (228 damaged by wild boar)	2 sites: 16 blocks without *C. ladanifer* ($A_{1–4}$, $B_{1–4}$, $C_{1–4}$, $D_{1–4}$). 16 blocks with *C. ladanifer* ($A_{1–4}$, $B_{1–4}$, $C_{1–4}$, $D_{1–4}$)	21–23 December 2020	29 May 2022 (17 months)

In experiment 2 with *C. ladanifer*, 1200 *Q. suber* saplings, which were about one year old, were planted in December 2020; 600 under the shade of rows of C. *ladanifer* (Table 3, Figures 2 and 3b) and 600 saplings on an open site (Figure 3a). The rows of *C. ladanifer* were about 2 m high, 2 m thick and 80 m long. The space between the rows was around 3.5 m (Figure 2). *Q. suber* saplings were planted directly next to the *C. ladanifer* row (Figure 2) with 1 m spacing. They were planted in eight rows, including 75 plants each. For statistical analysis, the samples were grouped into 16 replicates. All saplings were marked with a stick on the ground next to them.

Figure 2. Photograph of shrub rows of *C. ladanifer* taken on the plantation site. Photo taken at midday on the winter solstice shows the projection of the shade of shrubs. The plantation sites are located close to the shrubs so trees can benefit from the shade as much as possible.



(**a**) (**b**)

Figure 3. Aerial satellite view of site without C. ladanifer 1 (**a**) and site with *C. ladanifer*; (**b**) with the location of A,B,C,D blocks of experiment 2. In total, 600 Q. suber tree saplings were planted in each part, a total of 1200 plants.

In experiment 2, on the site without *C. ladanifer* (Figure 3a), one-year-old *Q. suber* saplings were planted in lines with a 1 m spacing in four areas distributed over a ridge. Inside each area, A, B, C and D, four rows of saplings were planted, resulting in a total of 16 blocks (Table 3).

Although the whole farm was not grazed during the time of the study, the site of experiments 1 and 2 without *C. ladanifer* rows were fenced to be protected from wild boar. However, in 2019, wild boar managed to enter the fenced areas damaging several plants.

The area with rows of *C. ladanifer* was not fenced, thus more plants were damaged by the wild boar. Close monitoring was performed to identify which trees were damaged and uprooted by the wild boar. Plants were considered damaged when clear marks of wild boar destruction were visible, which led to the removal of the sapling and the marking stick; these plants were removed from the analyses. Saplings were recorded as dead when stems were completely dried out and no green leaves were visible.

2.3. Microclimatic Characterization—Complementary Data

To further characterize the tested areas, we measured the complementary data using 25 soil probes (product model: Parrot flower power TM), which monitored soil moisture (10 cm depth) and air temperature in the first 10 cm depth of the soil. In experiment 1, four to five probes were installed in each of the four sites with different microclimatic conditions, recording data from February to September 2019. In experiment 2, seven probes were installed, recording data in April, May and June 2019.

The average temperature for each site, measured at soil level, is presented in Figure 4, showing that the ridge area has the highest average temperature, and the shrub area has the lowest, with a difference from 1 °C to 3 °C from March to May. From May to August, in the absence of data for shrub areas, the lower average temperature was measured in the north-facing slope, followed by the waterline area. Figure 5 shows that the north-facing slope and the area of *C. ladanifer* shrubs have the lowest maximum air temperature at soil level. The ridge area has lower maximum temperatures than the waterline area, possibly due to higher wind exposure. The data in Figure 6 show that north-facing slope and waterline sites have higher soil moisture values from February to May. The lowest values of soil water content are found in both ridge areas and in sites with *C. ladanifer* shrubs.

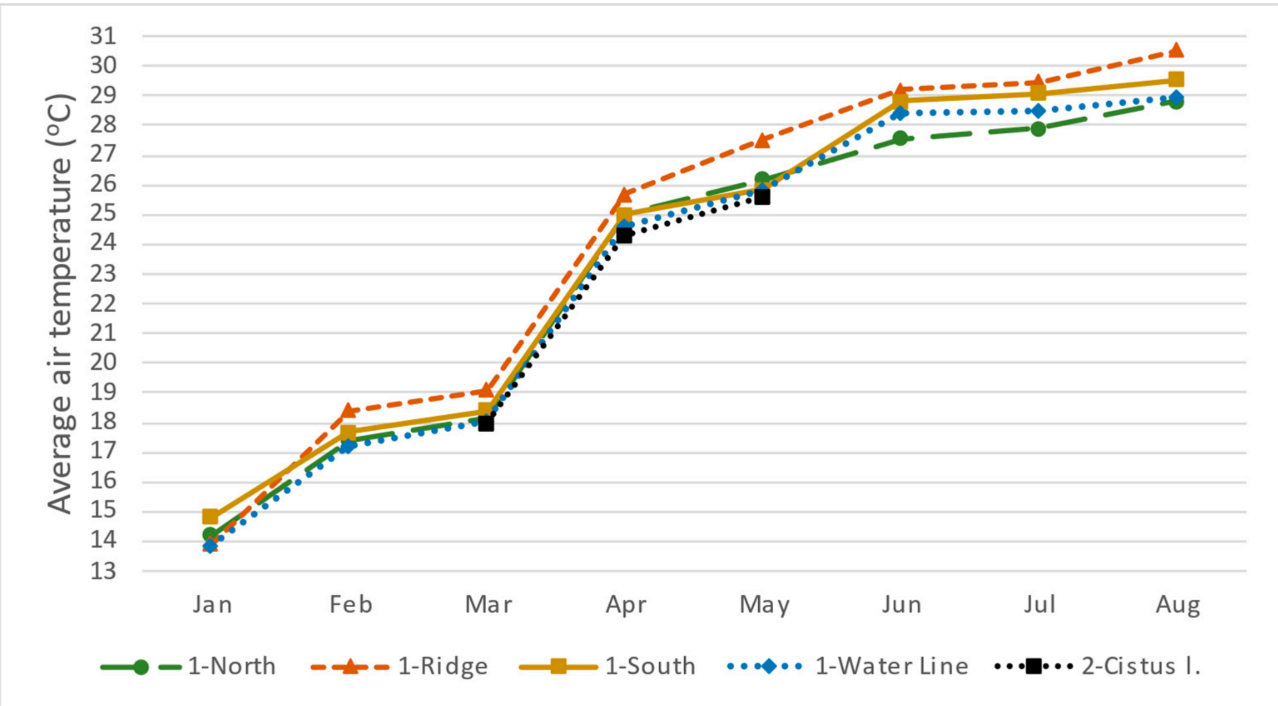


Figure 4. Average air temperature (°C) at soil level measured with 25 probes from February to September 2019 in experiments 1 (without *C. ladanifer*) and 2 (with *C. ladanifer*).

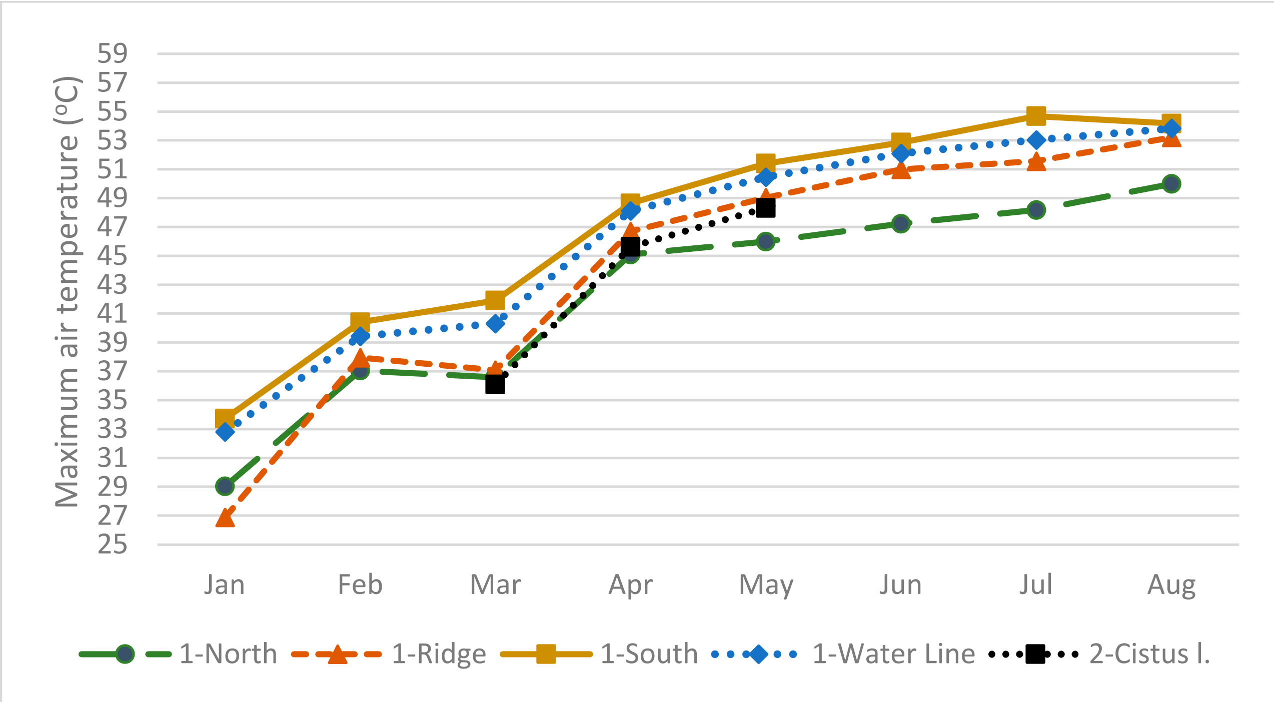


Figure 5. Maximum air temperatures measured with 25 probes from February to September 2019 in experiments 1 (without *C. ladanifer*) and 2 (with *C. ladanifer*).

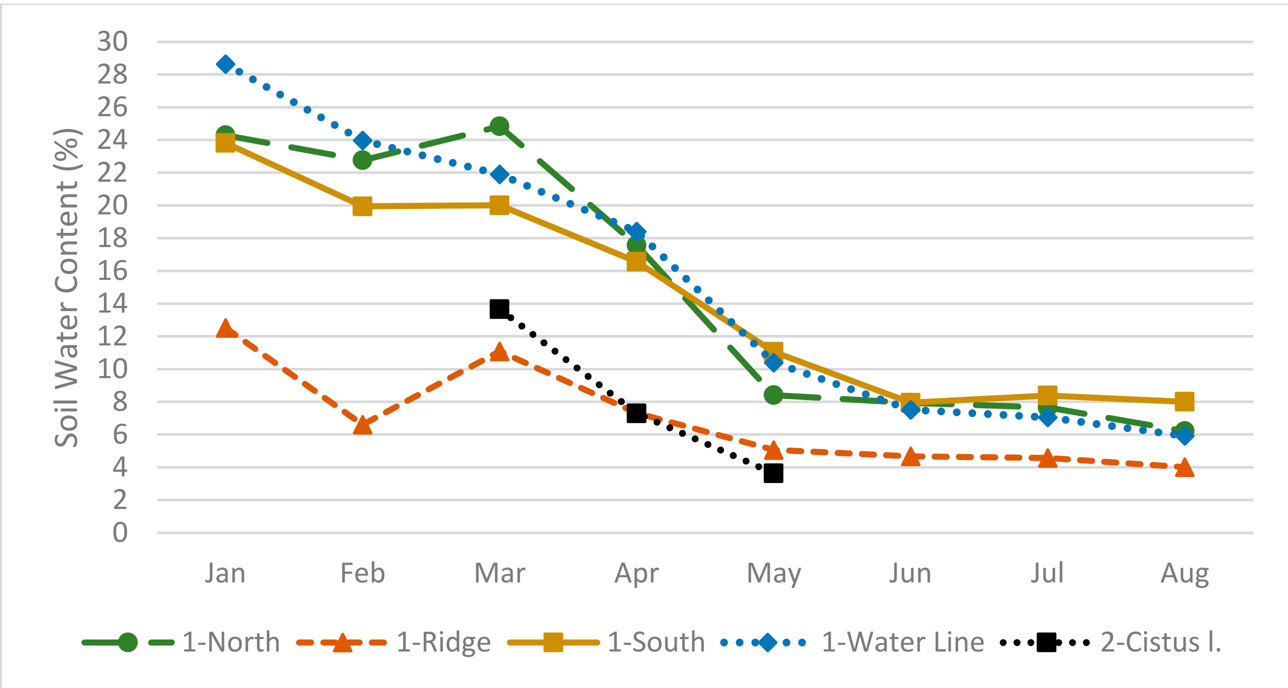


Figure 6. Average soil water content (%) measured with 25 probes from February to September 2019 in experiments 1 (without *C. ladanifer*) and 2 (with *C. ladanifer*).

2.4. Statistical Analysis

In experiment 1, the Kruskall—Wallis test, an extension of the Mann–Whitney test was used to test the statistical differences between the different microclimatic conditions. In experiment 2, the differences in tree survival rates in the site with and without *C. ladanifer* were tested using a non-parametric test (Mann—Whitney Test, significant for $p < 0.05$)

to account for the non-Gaussian distribution of the data. These statistical analyses were performed using CRAN software R, version 4.0.2 (R Core Team, 2020).

3. Results

The survival of *Q. suber* saplings three years (36 months) after plantation was significantly different (Kruskal–Wallis test; *p*-value = 0.0315) in the four sites with different microclimatic conditions (experiment 1, Table 3). The survival rate of *Q. suber* saplings in the water line was 45% and was 35% on the north-facing slope, whereas on the south-facing slope, it was around 15% and in the ridge area around 5%.

Table 4 and Figure 7 present the pairwise comparisons of *Q. suber* survival rates in different microclimatic conditions. Survival of Cork oak in the water line and on the north-facing slope was significantly higher than on the ridge.

Table 4. Differences in Cork oak survival rate between the planting sites with different microclimatic conditions using the percentage of survival. Values indicate the mean and standard deviation. KW: Kruskal–Wallis test. Df: degrees of freedom. *p*-value: significance of the test, $p < 0.05$ (in bold).

Planting Sites	Number of Blocks	Total Number of Trees	Survival Percentage	KW	df	*p*-Value
Water line	4	20	45 ± 19.15	8.84	3	0.032
North	4	20	35 ± 10			
South	4	20	15 ± 19.15			
Ridge	4	20	5 ± 10			

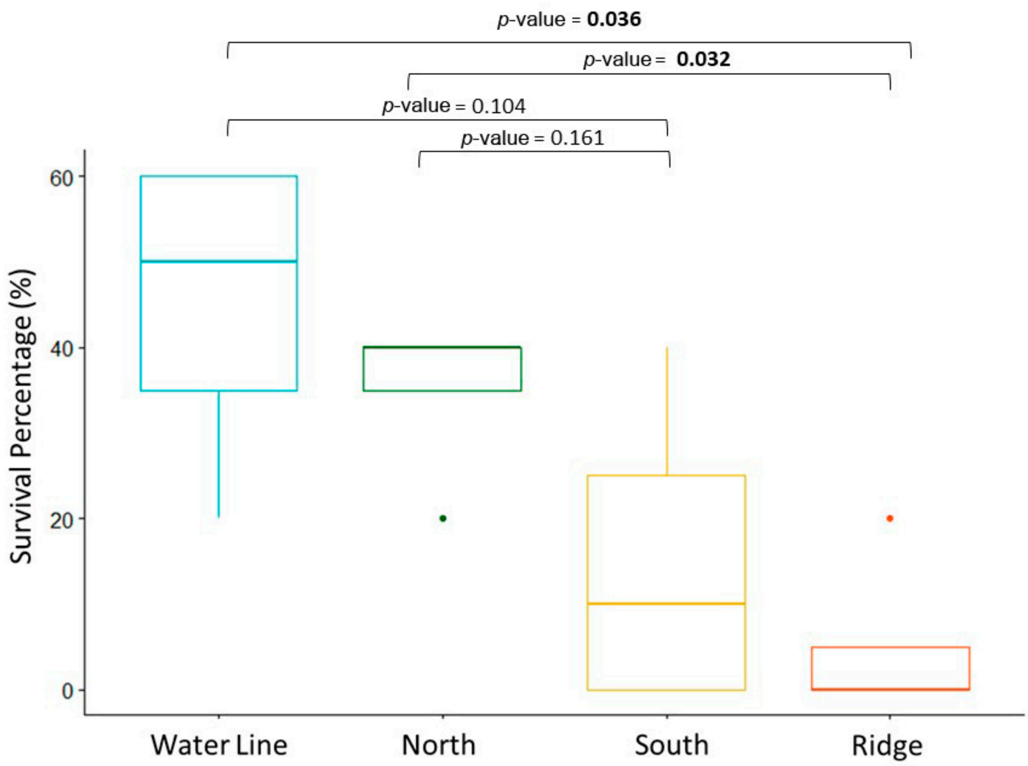


Figure 7. Differences in survival rate of *Q. suber* saplings between the planting sites with different topographic conditions. Values indicate the mean and standard deviation. Kruskal–Wallis chi-squared 8.84 with *p*-value: significance of the test (significant for $p < 0.05$ in bold).

The results showed a significant difference in survival rate of *Q. suber* between the area with and the area without *C. ladanifer* rows (Mann–Witney test, $p = 0.027$). After 17 months of plantation, in areas with rows of *C. ladanifer* the survival rate of *Q. suber* was

46% on average, while in areas without *C. ladanifer*, the survival rate was 35% on average (Table 5, Figure 8).

Table 5. Differences in Cork oak survival rate between the planting sites with and planting sites without *C. ladanifer*. Values indicate the mean and standard deviation. Inside brackets are the 95% lower and upper confidence intervals and the standard error. W: the value of the Mann–Witney test. *p*-value: significance of the test. Significant for $p < 0.05$ (in bold).

		N of Blocks (with *C. ladanifer*/without *C. ladanifer*)	N of Total Samples (with *C. ladanifer*/without *C. ladanifer*)	Measurements			
				With *C. ladanifer*	Without *C. ladanifer*	W	*p*-Value
Survival percentage (%)	All treatments	16/16	438/534	46.08 ± 14.09 [38.32, 53.84, 3.64]	34.68 ± 15.48 [26.16, 43.2, 4]	69	**0.027**

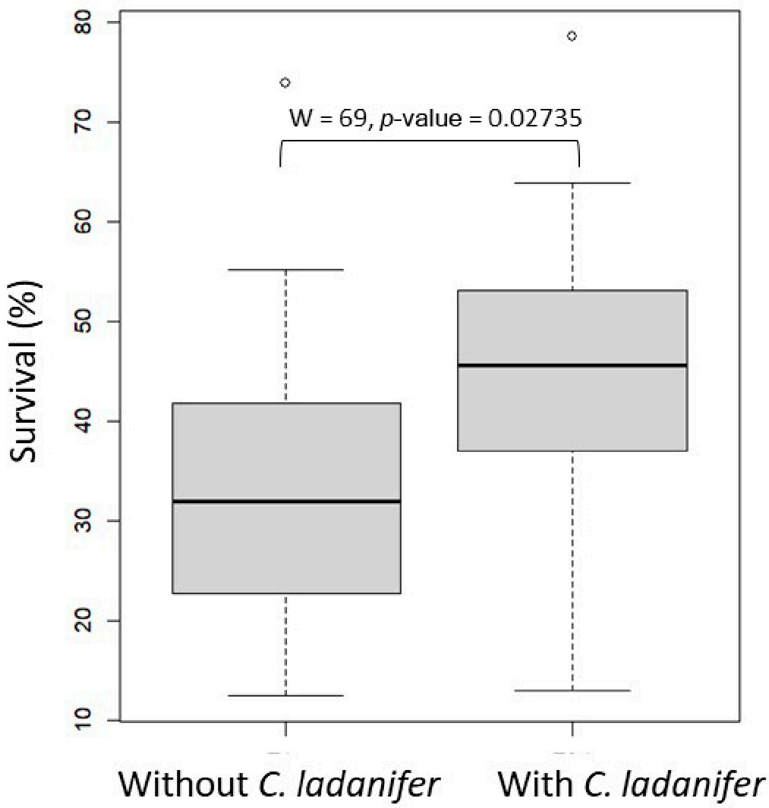


Figure 8. Difference in *Q. suber* survival rate in the open (without rows of *C. ladanifer*) and with the shade of *C. ladanifer* rows oriented east-west.

4. Discussion

This study found that the topography had an effect on the survival of *Q. suber* saplings three years after plantation. Other studies have previously identified the important effect of topography on tree seedling performance, tree recruitment and tree density, showing that microclimates should be considered when it comes to forest management [34,55–59]. Specifically, this study shows the importance of microclimatic conditions created by topography on a local scale for *Q. suber*, one of the dominant species of Mediterranean evergreen oak forests and wooded pasturelands. While we found significant differences in sapling survival rates between the ridge area and the north-facing slope and water line, there were no statistical differences between the north-facing and south-facing slopes. The north-facing slopes had lower maximum temperatures when compared to south-facing slopes, but on the other hand, soil moisture is not significantly different between the two types of slope. Tree mortality rates, namely in *Q. suber*, can be caused in particular by high temperatures or water scarcity and these results reinforce the fact that water scarcity is the main limiting factor for sapling survival in the present climate.

Quercus suber saplings had an increased survival rate in the shade of *C. ladanifer* shrubs when compared to plantation in an open area. While some studies indicate that shrubs have a facilitation effect on tree survival [38–41], other studies indicate that they have a competing role, highlighting that the relation between shrubs and trees is very dynamic and non-linear [45]. This facilitating effect may be a result of protection from heat and radiation, since Ghouil et al. (2003) show that temperature, when in combination with drought, can create significant stress, reducing photosynthesis in the seedling and sapling stages. Later on, when plants are more resistant and competition with *C. ladanifer* ensues [44], it may be more beneficial to shred the shrub rows and eliminate competition, whilst providing additional mulch and organic material to the soil.

According to Simões et al. (2016), shredding in between the shrub patches and around the trees is more efficient for tree regeneration and growth than plowing. In the context of grazing exclusion and to maximize tree growth, regeneration and ecosystem services, the same authors suggest that shredding should be repeated every seven years. This could be the appropriate timing to eliminate the shrub rows of *C. ladanifer* after the *Q. suber* tree establishment.

This plantation with shrub management design is compatible with the proposal by Simões et al. (2016) and, moreover, shrub management in rows is easier for tractor handling, reduces damage to trees during shredding and decreases costs by reducing the shredded area when compared to shredding the whole field. After the rows of *C. ladanifer* are shredded, competition is eliminated and the generated mulch will increase moisture in the soil [60,61]. Shrub rows create shade and also windbreak, which reduces soil evaporation and plant evapotranspiration. Furthermore, shrub rows have a beneficial effect on biodiversity and conservation by increasing structural diversity and a heterogeneous mosaic in the landscape, which creates shelter, protection and a habitat for wildlife [47,62].

Despite the positive facilitation effect in the initial stages of development of *Q. suber* saplings, Smit et al. (2007) state that shrub protection may foster the presence of rodents and thus reduce the presence of acorns, hence potentially reducing natural regeneration. This suggests that the positive facilitating effect observed in this study with planted saplings may not be observed in operations using acorns. In this context, it would be relevant to test the allelopathic action of *C. ladanifer* and its toxicity effect caused by the presence of flavonoids, which have been reported as inhibitors of seed germination of herbaceous species (e.g., *Cynodon dactylon* and *Rumex crispus*) [63] and *C. ladanifer* itself [64]. To our knowledge, no specific studies have addressed the allelopathic effect of *C. ladanifer* on the seed germination of *Q. suber* or other trees. If there is a toxicity effect of *C. ladanifer* that eventually impacts the growth of *Q. suber* saplings, our results show that the positive effects of the shrub's proximity outweigh the eventual negative effects in the 17 months of tree growth. Future research should observe the role of shrub rows over a longer period to further understand the trade-offs of tree–shrub interactions in order to provide management recommendations when using shrub rows to support the afforestation of *Q. suber*.

Further positive side-effects can be studied regarding shrub rows as a management tool to prevent erosion, create windbreaks and produce fiber for mulching and to increase soil organic matter. Future studies can also address shrub rows in contour lines or Keyline [65], since this is an innovative way of preparing terrain and placing trees for erosion control and rainwater harvesting, namely in combination with swales. Since the facilitating role of shrubs has been identified for several *Cistus* and also for several other shrubs in the creation of late-successional Mediterranean species [39], this strategy of using shrub rows can be replicated and used in the management of Montados, Dehesas and other Mediterranean land uses in areas where other shrub plant communities are found and the conflict of fuel management is present, together with the need to restore degraded land, increase ecosystem resilience and create climate-smart agroforestry ecosystems.

5. Conclusions

In this study, we observed the effect of topographic microclimates on the success of afforestation of *Q. suber* and tested a shrub management design that creates microclimatic conditions and shelter for *Q. suber* saplings. Topographic microclimates showed a significant effect on the survival rate of *Q. suber* plantations, namely in the ridge site; the tree survival rate three years after planting was an average of 5%, and in the thalweg/water line site was an average of 45%. Regarding the creation of microclimates to support afforestation using shrub rows, there was a beneficial effect of shrub rows on the survival rate of *Q. suber* saplings planted in the shade of *C. ladanifer*, leading to an 11% increase in tree survival rates in the first 17 months on our study site. This study shows that keeping rows of *C. ladanifer* shrubs oriented east-west and planting *Q. suber* in their shade after shredding in the interrow had, in the first 17 months, positive effects on the survival rate of tree plantations when compared to eliminating the shrubs of *C. ladanifer* before planting. Therefore, in the first year and a half, shrubs can be managed to increase *Q. suber* afforestation success in Mediterranean climate regions.

These results follow previous works that showed that tree density and, in particular, seedling performance is particularly affected by microclimates created by topographic conditions and other plants [37,57,58]. Tree plantations should be carried out with additional treatments or climate adaptation measures in areas where conditions are more adverse for the trees, namely when soil quality is lower and exposure to drought and heat is higher [29,32,33,66]. In such sites, microclimates can reduce exposure to climate variables, creating different conditions for tree survival on finer scales [36,58,59,67].

This study was developed in real farm conditions, which, on the one hand, limited the control of natural factors but, on the other hand, presented real farm management results, showing practical field feasibility and measures that can be easily replicated by other landowners and farmers in Mediterranean evergreen oak forests, Mediterranean wooded pasturelands, Montado/Dehesa of evergreen *Quercus* spp. or analog Mediterranean climate agro-silvo-pastoral systems.

The pioneer plant *C. ladanifer* occupies large areas in the Montado ecosystem whenever there is a lack of grazing, abandoned degraded land, soil erosion and lack of understory management [26]. In Portugal, the area of shrubland occupies 12.4% (11,075 Km^2) of the total area of the country's mainland [54]. The need for fuel management and shrub discontinuity in the understory of cork oak and holm oak trees is necessary for the prevention of large fires [68]. At the same time, the low rates of survival in afforestation and reforestation investments are significant and, in the context of climate change scenarios RCP 4.5 and RCP 8.5, the survival rates are expected to decrease [19,69,70]. In this context, this study brings new empiric results on the facilitation role of shrubs (*C.ladanifer*) on *Q. suber* plantations, with a specific shrub management design that can represent a proposal for land restoration and climate-smart agroforestry in cork oak woodlands, Montados and Dehesas.

Microclimates can be used not only to support afforestation planning but also as a climate adaptation measure to increase afforestation success in areas where plant survival is low. Future studies can help in understanding the extent of microclimate potential in practice, namely by studying the use of shrubs in rows in the long term and the practical ways how to manage these to optimize the benefit for afforestation, silvo-pastoral management and landscape restoration.

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