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Growth and survival in *Quercus ilex* L. seedlings after irrigation and artificial shading on Mediterranean set-aside agricultural land

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Abstract – Considerable quantities of agricultural land are being transformed into forested lands in E.U. countries. To assess afforestation practice, we analyzed the growth and survival of 800 *Quercus ilex* sp. *ballota* seedlings in set-aside agricultural land under semi-arid Mediterranean climate conditions in central Spain. The survival and growth of the seedlings were monitored for 3 years after planting with an experimental design that included all four combinations of: i) irrigation or no irrigation during the dry season; and ii) artificial shading or no shading. Significant differences in survival and growth (height, stem diameter and crown projected area) were found among treatments. Survival was lowest (53 %) in the control plots, and very similar (around 93 %) for the irrigation, shade and combined treatments. Most of the mortality occurred after the first dry season. The high survival rate in irrigated but not shaded plots coincided with a thick layer of the weed *Amaranthus retroflexus* L. (in the first dry season). Seedling growth was greatest on average under irrigation and shade conditions. Shade was found to have a significant effect for all growth measurements, while irrigation alone only affected stem diameter growth and crown projected area in interaction with shade. Growth measurements were correlated to microclimatic conditions in the plots as measured by the amounts of water and actual evapotranspiration. We conclude that the attenuation of summer stress must be considered in the early stages of successful plantation practice of set-aside agricultural land in a dry environment. (© Inra /Elsevier, Paris.)

agricultural land / growth / irrigation / shade / survival

Résumé – Croissance et survie de plantules de *Quercus ilex* L. après irrigation et ombrage artificiel sur des terres agricoles méditerranéennes en déprise. En Europe, de nombreuses terres agricoles ont été boisées. La politique agricole de l'Union européenne subventionne actuellement la transformation de terres cultivées en forêt avec une attention spéciale accordée aux espèces feuillues. Pour évaluer les pratiques de boisement, nous avons analysé la croissance et la survie de 800 plants de *Quercus ilex* sub-espèce *ballota* sur une ancienne terre agricole soumise aux conditions climatiques semi-arides du climat méditerranéen du Centre de l'Espagne. Après plantation, la survie et la croissance des plants ont été suivies pendant trois ans. Le dispositif incluait quatre combinaisons : 1) irrigation ou non irrigation pendant la saison sèche, 2) ombrage artificiel ou non ombrage. Les trai-

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tements ont différé en évapotranspiration potentielle (ETP) ($p < 0,0002$) et évapotranspiration réelle (ETR) ($p < 0,0001$). Ces traitements ont induit des différences dans la production d'adventices ($p < 0,0001$) lesquelles étaient uniquement affectées par l'irrigation. L'irrigation, l'ombrage et l'interaction entre l'irrigation et l'ombrage ont induit un effet positif sur la survie des plants (valeurs-p plus petites que 0,007, 0,0007 et 0,01 respectivement). Les plus grandes différences en terme de survie des plants sont apparues au cours de la fin de la première saison sèche (*figure 1*). La survie ne différait cependant pas de façon significative entre les traitements d'irrigation, d'ombrage et combiné. En revanche, chacun des trois traitements ont induit de manière significative moins de mortalité que le témoin. La forte survie des plants du traitement irrigué non ombragé coïncidait avec une forte couverture des adventices (*Amaranthus retroflexus* L.) au cours de la première année. Des effets significatifs des traitements sur la croissance des plants ont été notés : $p < 0,002$ pour le diamètre de la tige, et $p < 0,0001$ pour la hauteur et la surface projetée du houppier (SPH) (*figure 2*). L'effet de l'ombrage était significatif pour toutes les mesures de croissance ($p < 0,003$ diamètre de la tige et $p < 0,0001$ pour la hauteur et la SPH). L'irrigation seule a eu un effet significatif sur le diamètre de la tige ($p < 0,03$) et l'interaction entre l'irrigation et l'ombrage a produit un effet significatif sur la croissance en diamètre ($p < 0,04$) et en SPH ($p < 0,02$). À la fin de la première année, le plus fort diamètre correspondait aux parcelles irriguées non ombragées. Toutes les variables mesurées de la croissance étaient correlées avec la quantité d'eau et avec l'ETR (r compris entre 0,35 et 0,78, et valeurs-p entre 0,01 et 0,0001). Les coefficients de corrélation étaient plus élevés de 50 % pour la quantité d'eau que pour l'ETR. Nous concluons qu'il faut chercher à réduire le déficit hydrique des plants si l'on veut améliorer le succès des plantations en terres agricoles dans des milieux secs. L'irrigation des plants pendant l'été crée des conditions qui permettent la survie des plants après plantation. En deuxième et troisème année, les traitements d'irrigation et/ou ombrage augmentent la croissance des plants.

déprise agricole / croissance / irrigation / ombrage / survie

1. INTRODUCTION

About 600 000 ha of agricultural land are abandoned every year in Europe [8]. Revegetation of this land is therefore an important ecological and socioeconomic issue [11]. The agricultural policy of the European Union currently subsidizes the transformation of cropland into forest, with special attention paid to native broadleaf tree species [7]. In a Mediterranean context these efforts, however, run up against a very limited experience in revegetation with Mediterranean broadleaf species, as reforestation in the last decades has been basically made with conifers [10].

This paper focusses on the afforestation of set-aside agricultural land in Mediterranean areas using sclerophyllous oak *Quercus ilex* L. seedlings. This tree dominates a large part of the natural forests and woodlands in western European and African Mediterranean dry regions [27]. Previous studies have shown the high mortality levels experienced by *Q. ilex* plantations during the first year [1, 23]. In the context of international scientific awareness of Mediterranean woodlands and forests [20], these considerations have encouraged studies on the afforestation of set-aside agricultural land in Mediterranean environments with native sclerophyllous oak species.

Water and radiation have been shown to be key limiting factors for vegetation establishment in Mediterranean ecosystems [6, 33]. Our objective is to quantify the effects of two techniques (irrigation and shading) on the survival and growth of newly planted *Q. ilex* seedlings. We hope that the results of this study may form a critical foundation for the success of revegetation projects in Mediterranean areas.

2. STUDY SITE

The study site was located at La Higueruela, the CSIC experimental farm in Toledo, central Spain (40°3′N, 4°26′W, altitude 450 m). The climate is semi-arid continental Mediterranean, characterized by a long, hot and dry summer that imposes severe water stress on the vegetation. During the experiment, precipitation and mean temperature were the following: 339.4 mm and 15 °C for the first year, 125.6 mm and 16.8 °C for the second year, and 397.8 mm and 16.3 °C for the third year. The soil is a luvisol type, and derives from arkosic parent material. The use of the land in the area is mostly agricultural; however, extensive sheep and goat grazing and hunting also take place.

3. MATERIALS AND METHODS

3.1. Experimental design

The study was conducted on a 1-ha plot on former cropland which had been cultivated for grain for many years until afforestation took place in the winter of 1993. The experimental design included four combinations of artificial shade (presence or absence) and summer irrigation (presence or absence), with four replicates per combination. Fifty 1-year-old *Quercus ilex* L. sp. *ballota* (Desf.) Samp. seedlings (nomenclature following Castroviejo et al. [5]) were planted with a regular distribution in each of the 16 plots. The plots were 10 × 10 m, and were distributed over 0.5 ha of land. The seedling density, i.e. 5 000 per ha, is equivalent to that found in the shrub layer of natural *Q. ilex* woodlands [14]. The seedlings were planted with 20-cm diameter plugs buried 40 cm deep.

The treatments were: 1) sprinkler irrigation at the peak of the dry season (60 mm twice, in July and August; 120 mm year^{-1} total), the water being added uniformly to the entire area; 2) artificial shading (black polyethylene net placed 2 m above the ground, which reduced incident radiation by 68 %). Herbivores were excluded from all plots because hares and rabbits cause severe damage to seedlings (up to 20 % unprotected seedlings were eaten in 1 week at our site).

We calculated the amount of water and evapotranspiration (PET and AET) in the plots according to the different treatment conditions (Penman-Monteith equation; [29]). Treatments differed in ET ($P < 0.0002$ for PET and $P < 0.0001$ for AET). The amounts of PET (mm year^{-1}) in the treatments averaged: 1 344.5 for the control, 1 362 for the irrigation, 1 151 for the shade, and 1 119 for the combined treatment. The amounts of AET (mm year^{-1}) averaged: 409.6 for the control, 519.8 for the irrigation, 414.3 for the shade and 552 for the combined treatment. We also measured the dry weight of aboveground weed biomass production after the first dry season (September 1993) in the plots, because preliminary observation suggested their possible importance for seedling survival. The biomass was clipped in 32 0.5-m^2 quadrats between the seedlings with two per plot. The irrigated and unshaded plots developed a thick and ca. 40-cm tall layer of the weed *Amaranthus retroflexus* L. (taller than the seedlings). This is a C4 phenologically late species, and was responsible for most of the summer weed biomass production. There were significant differences for weed production among treatments ($P < 0.0001$). Biomass was affected solely by irrigation ($P < 0.0001$). Actual biomass values (gm^{-2}) were: 78.01 ± 39.05 for the control, 167.77 ± 43.39 for the irrigation treatment, 67.21 ± 31.4 for the shade treatment, and 126.96 ± 27.91 for the combined treatment.

3.2. Measurements

The parameters examined for the different treatments for the 3 years were: 1) seedling survival, assessed once per season and year (12 survival counts in total); 2) seedling growth, measured yearly as: i) seedling height; ii) stem diameter (2 cm above ground level); and iii) crown projected area (CPA) measured as the elliptical surface of the crown projected onto the ground; 3) plot cover by the seedlings. This plot cover in an afforested plot after a year is the sum of the CPA (2.iii) of the surviving seedlings (1).

3.3. Data analysis

We used two-way ANOVAs to test the effects of irrigation, shade and the interaction of irrigation and shade on seedling survival and growth. For comparisons between treatment combinations, we used Tukey's tests with a nominal P value of 0.05. Finally, we used correlations to highlight the relationships between seedling growth and microclimate conditions in the different treatments. For the correlations, $n = 16$ plots × 3 years = 48.

4. RESULTS

4.1. Seedling survival

Irrigation, shade and the interaction of irrigation and shade had a positive effect on survival (the ANOVA analyses indicated P values smaller than 0.007, 0.0007 and 0.01, respectively). Most differences in seedling survival appeared by the end of the first dry season (*figure 1*). Survival was not significantly different between the irrigation, shade and combined treatments; however, all three treatments had significantly less mortality than the control. One year after planting, the treatments reduced the mortality rates by one order of magnitude from the control plots (4 and 40 %, respectively). After the first year, new mortality counts were not significantly different among treatments.

4.2. Seedling growth

There were overall differences for seedling growth measurements ($P < 0.002$ for stem diameter and $P < 0.0001$ for height and CPA; *figure 2*). However, significant differences did not hold for all between-treatment comparisons. The effect of shade was significant for all growth measurements ($P < 0.0003$ for stem diameter and $P < 0.0001$ for height and CPA). Irrigation alone had a significant effect on stem diameter ($P < 0.03$), and the interaction of irrigation and shade was significant for stem diameter ($P < 0.04$) and CPA ($P < 0.02$) growth. At the end of the first year, the greatest stem diameter increment corresponded to the unshaded irrigated plots, and the effect of irrigation alone was significant.

The comparison among treatments of plot cover by the seedlings (*figure 2d*), a measure that combines growth and survival, was

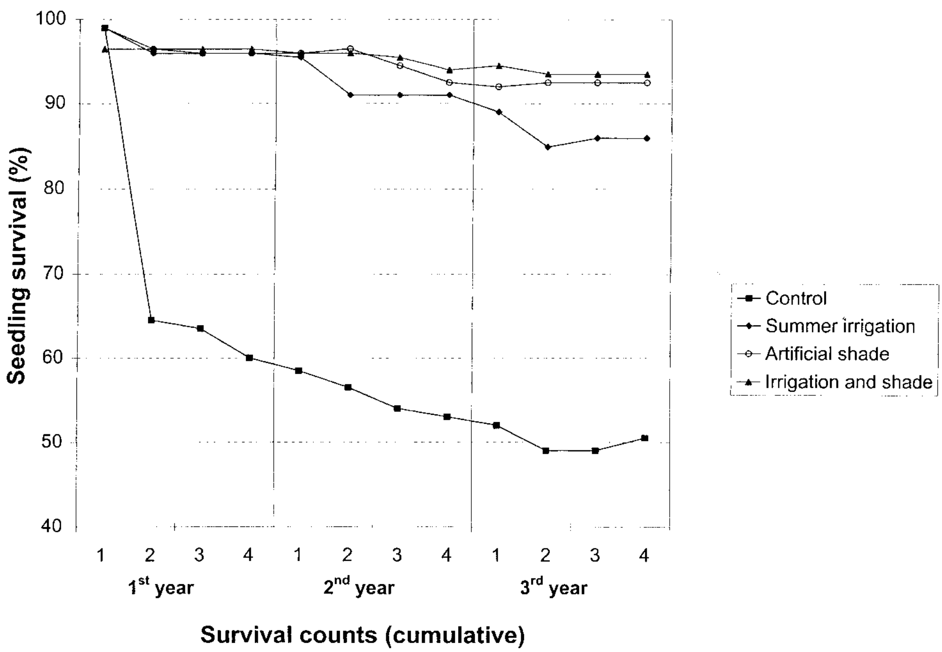

Figure 1. Percentage of oak seedling survival (cumulative frequencies after different counts within 3 years) in each treatment. Segments 1, 2, 3 and 4 correspond to early summer, early autumn (after applying the irrigation treatment), winter and spring survival counts, respectively.

highly significant. Again, few between-treatment comparisons were statistically different. The effects of irrigation, shade and the interaction of irrigation and shade were significant. All seedling growth measurements were significantly related to the amounts of water and AET in the plots as conditioned by the treatments (r ranged between 0.35 and 0.78, and P values between 0.01 and 0.0001). The correlation coefficients for the amount of water were 50 % greater on average than for AET. However, oak growth was not related to PET.

5. DISCUSSION AND CONCLUSION

Difficulties with natural regeneration of *Quercus* spp. have been described in North America, Europe and Asia [3, 15, 28]. These and other authors have proposed several hypotheses to explain this phenomenon such as limited availability of water and nutrient resources, competition and predation. This study demonstrated that a 120 mm year^{-1} irrigation in the peak of the dry season increases survival rates by a factor of 10, similarly to continuous artificial shade. Although a number of studies have demonstrated weed competition to reduce plantation survival and growth [9, 21, 22, 25], we did not observe such an effect in the irrigated plots, which exhibited the highest weed biomass. An important finding was that the first dry season is the key for survival of *Q. ilex* seedlings, after which mortality scarcely increased even in the control plots.

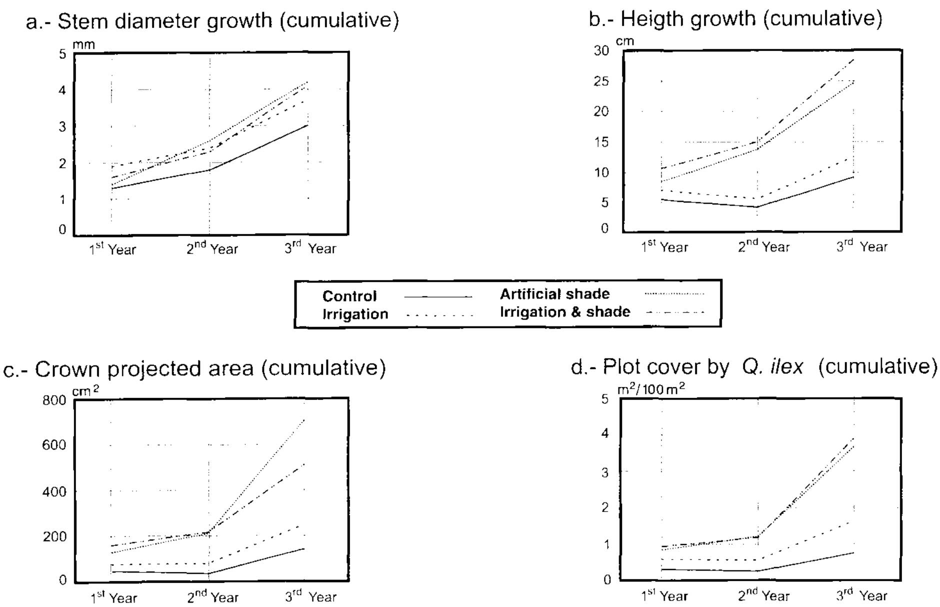

Figure 2. Annual growth (cumulative) of the *Q. ilex* seedlings during 3 years for: a) stem diameter; b) height; c) crown projected area; and d) plot cover by *Q. ilex* seedlings. These measures represent increments. The initial size values of the seedlings averaged 3.05 mm for stem diameter, 36.89 cm for height, 147.55 cm^2 for CPA, and 0.18 % for plot cover.

Baeza et al. [1] found a 65 % mortality for *Q. ilex* seedlings 3 years after being planted in afforested plots under a precipitation regime similar to that on our study site. This figure is consistent with the results from our control plots. These authors found a 30 % mortality in plots with light irrigation in summer. However, the mortality in our irrigation treatment was lower (14 % of the seedlings). Terradas and Savé [31] indicated that drought stress is a key abiotic factor involving the survival and distribution of *Q. ilex* forests. Lansac et al. [12] observed a peak water stress in *Q. ilex* at the end of the summer coinciding with the highest period of mortality in our study. Baeza et al. [2] also measured the height increment of the seedlings. Their final values ranged between 19 and 50 cm, with an average increment of 83 % and a 128 % increment during summer irrigation (calculated by the present authors from their published data). Both rates are greater than ours.

One year after planting, the greatest increment in stem diameter corresponded to the irrigation treatment (1.9 mm year^{-1}), whereas height and CPA increments followed the sequence control < irrigation < shade < combined treatment. McCarthy and Dawson [17] observed in other *Quercus* species a reduction in the root/shoot biomass ratio with shade. Enhanced secondary and root growth are mechanisms which are considered to allow plants to thrive better under stressful conditions [13, 24, 26, 30, 32]. Mayor et al. [16] measured a stem growth of 1.04 mm year^{-1} for *Q. ilex* seedlings under an irrigation treatment of 20 mm per week during the summer, while oaks in control plots increased their stem growth by 0.56 mm year^{-1}. Carten-Son et al. [4] and Zhang and Romane [34] found that oaks increased their stem growth in rainy late springs and summers. In our study, annual growth of the seedlings across treatments and across 3 years of experimentation were correlated to the amount of water in the plots, most of which was precipitation. Potential evapotranspiration was not found to be related to growth. However, within 1 year, PET reduction by artificial shading increased growth (*figure 2*) besides survival rates.

We conclude that summer irrigation provides the necessary conditions for seedling survival after plantation, and that after establishment (second and third years) irrigation and/or shade treatments increases growth. The results obtained in this study may serve as a reference for testing new and for improving existing techniques [18, 19] for successful afforestations with non-conifer native Mediterranean species.

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