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Original article

Holm oak (*Quercus rotundifolia* Lam.) and Aleppo pine (*Pinus halepensis* Mill.) response to different soil preparation techniques applied to forestation in abandoned farmland

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Abstract – This paper evaluates the effectiveness of several soil preparation procedures in forestation establishment and development in localized farmland, within a territory in ombroclimatic transition between dry and semi-arid, located in Granada, southeastern Spain. An experiment in the forestation of Holm oak (*Quercus rotundifolia* Lam.) and Aleppo pine (*Pinus halepensis* Mill.) was set up, in which 8 different soil preparation techniques were used. The survival, total height and basal diameter of the plantation was monitored over a 5-year period (1996–2000). The statistical analysis of these parameters evidenced highly significant differences in the overall behaviour of the two sample forest species, related to changes in the prevailing environmental conditions in these territories and the type of soil preparation procedure applied. The overall results obtained for the three parameters analysed show the effectiveness of using backhoes for pit planting and linear rippering with a hydraulic structure to captures runoffs, in comparison to other preparations. Areal soil preparations, in particular, are not recommended.

forestation / semi-arid / soil preparation

Résumé – Réponse du chêne vert (*Quercus rotundifolia* Lam.) et du pin d'Alep (*Pinus halepensis* Mill.) à différentes techniques de préparation du sol pour le reboisement de terrains agricoles abandonnés. Dans ce travail on évalue l'efficacité de différents procédés de préparation du sol pour l'établissement et le développement d'un reboisement de terrains anciennement cultivés et situés dans un domaine ombrothermique intermédiaire entre le sec et le semi-aride, à Grenade, dans le sud-est de l'Espagne. Dans ce but, on a mis en place un reboisement expérimental de chêne vert (*Quercus rotundifolia* Lam.) et de pin d'Alep (*Pinus halepensis* Mill.) effectué selon 8 procédés différents de préparation du sol, et pour lesquels on a relevé la survie, la hauteur totale et le diamètre basal pendant une période de 5 ans (1996–2000). Les analyses statistiques ont mis en relief des différences significatives du comportement général des deux essences forestières testées et en relation avec les changements des conditions de milieu et des techniques de préparation du sol. Les résultats obtenus pour les trois paramètres analysés montrent l'efficacité des trous effectués à la pelle rétroexcavatrice et des sous-solages en ligne asssociés à une structure hydraulique qui récolte les écoulements, par rapport à d'autres types de préparation, notamment le travail du sol en plein dont l'utilisation est déconseillée.

reboisement / semi-aride / préparation du sol

1. INTRODUCTION

For decades the attempt to make farming profitable through extensive farming meant that a large amount of forest was brought under cultivation. Low crop productivity determined a large-scale abandonment of these lands that, unprotected by a vegetation covering and subjected to inclement Mediterranean weather, rapidly suffered serious erosion and desertification, highlighting one of the major environmental problems in the Mediterranean Basin today [14]. Faced with this environmental problem, the EU's Common Agricultural Policy adopted a series of environmental measures based on the implementation of programs that offered grants for investing in forests on farms. These programs aimed to promote forestation in order to restore natural vegetation in marginal farmland. They meant that thousands of hectares of farmland were able to recover their original forest nature through forestation.

Mediterranean ecosystems are especially resistant to intense human disturbance [5] and to climatic and socio-economic changes. However, if the degradation passes certain ecological limits, especially in arid and semiarid environments, only human intervention can reverse it, through restoration [1, 9]. In this sense, the abandoned farmland, submitted to intensive exploitation of its natural resources for generations, lost most of the characteristics and attributes of forest land. Moreover soil, as the principal support and sustenance of vegetation, is

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Figure 1. Study area location.

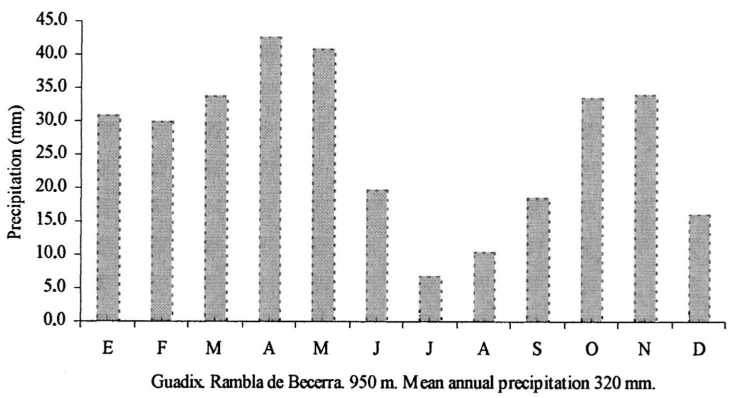

Figure 2. Distribution monthly average precipitation during the year.

also a primary factor in vegetation restoration. The soil of this marginal farmland is characterized by a loss of fertility, surface crusts, high insolations, lack of protection during torrential rain and an impoverished structure [2, 3, 8]. It therefore constitutes an accumulation of adversities that reforested vegetation must overcome. These adverse conditions are more serious in territories located in a dry, semi-arid environment where the lack of precipitation causes an edaphic hydric deficit in which water is the main limiting factor. The soil's biological potential could be established in terms of its hydric balance [13]. Given these conditions, planning a strategy for water use on each piece of land is a necessary first step towards considering the forestation of these territories. In this sense, soil preparation becomes highly relevant. As a reforestation technique, it improves soil receptivity by modifying its short-term properties. This is achieved by increasing the volume of useful soil, infiltration speed and the soil's water retention capacity by loosenign the soil and capturing runoffs, which improves moisture around the reforested seedling and helps to get the plantation established.

This paper compares several soil preparation techniques used in farmland forestation according to different response parameters in order to determine how useful each one would be as a management tool in ecology restoration plans.

2. MATERIALS AND METHODS

2.1. Study area and anthropic background

The experiment was set up in Rambla de Becerra (Guadix, Granada), an area in ombroclimatic transition between dry and semi-arid, located in Spain (Fig. 1), at an average height of 950 m. and coordinates 37° 26' N and 3° 05' W. The predominant soils are fluvisoles formed by periodical allumviums of sedimentary materials (sand, mud and gravel). The lack of precipitation is worth noting (392 mm in 1996, 478 mm in 1997, 393 mm in 1998, 114 mm in 1999 and 228 mm in 2000) (Fig. 2), although mean annual precipitation is 320 mm. Variations in temperature confirm the marked continental nature of the territory and can cause sporadic snowfalls during the winter months (absolute minimum winter temperature = –10 °C).

Table I. Technical characteristics of the soil preparations.

Treatments	Treatment	Machinery	Preparation surface (m^2/Ha)	Preparation depth (cm)	Action done on soil profile	Hydraulic structures
Punctual: Pit planting and construction of a plantation bench on the stirred soil	AH	– Portable screw auger with a two-cycle engine	Low (< 5%)	60	Mixture of horizons	No
	AM	– 240 HP tractor with two shanks modifed with side wings	Low (< 5%)	60	Mixed horizons	No
	AR	– 80 HP backhoe	Low (< 5%)	60	No mixed horizons	No
	ARM	– 80 HP backhoe with system for catching run-offs	Low (< 5%)	60		Microbasins
Lineal: Making furrows along the contour line	AV	– Farm tractor with reversible, double furrow moldboard plough	Medium (20–30%)	20	Mixture of horizons	Ridges
	S	– 286 HP bulldozer with two ripper placed 2m apart	Medium (20–30%)	60	No mixed horizons	No
	RA	– 286 HP bulldozer with ripper modified with side furrow moldboard	Medium (20–30%)	60	Mixture of horizons	Ridges
Areal: Ploughing the entire land surface with a tractor	LB	– Farm tractor with a 10-blade multiple furrow moldboard	Very high (100%)	25	Mixture of horizons	No

The area was used for cereal cultivation and grazing for at least 250 years [6]. In 1994, the public Administration bought this land when cultivation was abandoned. In the summer of 1995, the land was prepared for forestation after the first autumn rains.

2.2. Species description

Pinus halepensis Mill. (Aleppo pine). A colonizing arboreal species whose great capacity for expansion is enhanced by rapid longitudinal growth. It is very robust, has abundant annual fructification and a small pine kernel, as well as a large canopy and high germinative power. Of circum-Mediterranean distribution, the Aleppo pine is the *Pinus* genus species most widely found throughout the Mediterranean area. Its ecological behaviour allows it to be described as a heliophyte that is thermophilic and xerophilous. It is well adapted to droughts and can support annual precipitations as low as 150 mm. Temperature is one factor that can limit the distribution of this species. In particular, the average minimum temperatures of the coldest month can relegate this species to the Thermomediterranean and Mesomediterranean thermotypes. From an edaphic point of view, the Aleppo pine is not a demanding species. It can often be found in skeleton soils that are poor in nutrients. In our study area, the Aleppo pine is a native species that grows in an optimal area within its ecological distribution.

Quercus rotundifolia Lam. (Holm oak). The Holm oak is beyond doubt the most genuine of the Iberian Mediterraean forest species. It is the foundation of one of the most complex and mature ecosystems on the Peninsula. Its life strategy consists in a combination of many mechanisms that are adapted to Mediterranean climate-related edaphic conditions, such as the sclerophyllous nature of its leaves, its powerful root system, and the abundance of nutrient reserves in its fruit (acorns). Robust species, slow growth, enormously vigorous and indifferent to exposure, is generally held to be a light species in its mature state. However, considering the need its seedlings have of shade and soil (fresh and damp), when they develop in a warm climates with little rain or sunny orientations, it would be more appropriate to classify it as a medium light species during the first stages of its life. Indifferent to substrates, it grows in Thermomediterranean, Meso-Mediterrarnean and Supramediterranean thermotypes and extends to dry, subhumid and humid ombroclimates, although to survive it needs at least 300–350 mm. It can support the intense summer xericity that is characteristic of the Mediterranean climate. In our study area, the Holm oak is at the limit of aridity for its ecological distribution.

2.3. Soil preparation procedures

Eight soil preparation procedures were tested. They can be classified in 3 groups according to occupied surface (punctual, linear and areal). The technical characteristics for each group are outlined in Table I.

2.4. Forestation monitoring

The experiment was set up in an abandoned grain field. It consisted of three randomized blocks of 8 plots each, one for each soil preparation type, with three subrepetitions of each treatment. Each plot measured 1000 square meters and in each one 50 plants (25 Holm oaks and 25 Aleppo pines) were alternatedly planted.

The reforested vegetation was monitored to evaluate the effectiveness of the soil preparation for forestation establishment and development. The morphological parameters were studied by making a complete quantitative analysis of growth based on the total height and basal diameter of each plant. Likewise, forestation survival was monitored

Table II. Evolution of the mortality rates (mean ± standard error) for Aleppo pine (*Pinus halepensis*) and Holm oak (*Quercus rotundifolia*) in relation to the testesd soil preparations during the 5 year period of forestation monitoring (values are for six months, one year, and 5 year after planting). In one column, the numeric values followed by a letter (a, b) show significant differences ($P < 0.05$).

Treatments	*Quercus rotundifolia*			*Pinus halepensis*		
	6 months ± SE	12 months ± SE	60 months ± SE	6 months ± SE	12 months ± SE	60 months ± SE
Auger pit opening	1.3 ± 0.6	22.1 ± 7.8 a	63.1 ± 8.8 b	0	4.0 ± 1.7 a	9.3 ± 4.3 a
Mechanized subsoiling	0	18.6 ± 7.8 a	67.9 ± 8.8 b	0	0	6.6 ± 4.3 a
Backhoe subsoiling	0	12.1 ± 7.8 a	34.4 ± 8.8 a	4 ± 0.5	4.0 ± 1.7 a	4.0 ± 4.3 a
Backhoe subsoiling with microbasins	0	14.8 ± 7.8 a	36.3 ± 8.8a	0	0	8.0 ± 4.3 a
Ridges	0	17.7 ± 7.8 a	58.0 ± 8.8ab	0	5.3 ± 1.7 a	5.2 ± 4.3 a
Linear rippering with ridges	0	14.1 ± 7.8 a	35.3 ± 8.8 a	0	5.8 ± 1.7 a	8.3 ± 4.3 a
Linear rippering	0	23.4 ± 7.8 a	52.9 ± 8.8ab	0	1.3 ± 1.7 a	4.1 ± 4.3 a
Ploughing	0	49.6 ± 7.8 b	65.7 ± 8.8 b	1.0 ± 0.5	14.4 ± 1.7 b	40.3 ± 4.3 b
ANOVA test	$F = 0.85$ $p = 0.59$	$F = 2.03$ $p = 0.08$	$F = 1.74$ $p = 0.14$	$F = 5.32$ $p = 0.00$	$F = 5.18$ $p = 0.00$	$F = 5.83$ $p = 0.00$

by dead plant count, an essential parameter for assessing soil preparation effectiveness during the initial phase of each specie's establishment and adaptation to the environment. After planting in the autumn of 1995, these parameters were systematically measured during annual sampling campaigns at the end of winter and summer. During the first year, it was considered necessary to monitor the survival of 4 samples at the end of each season to determine initial mortality due to post-planting stress. Unfavourable weather conditions (periods of draught) can induce physiological stress once the plant passes the critical initial stage.

2.5. Statitistical analysis

The data obtained for each parameter was submitted to a parametric statitistical analysis based on the analysis of the variance (ANOVA) of two factors: treatments and time. Tuckey's test for multiple comparisons based on Student's t distribution was used to determine any significant differences in each case (post hoc tests).

Behaviour indexes were obtained for the height and diameter of Holm oaks and Aleppo pines in relation to the growth and survival parameters. This allowed us to evaluate the global effect of the treatments applied (Behaviour index = height (diameter) × survival in percentages at so much per one). Finally, the correlation between the behaviour indexes of both species was studied to determine the relation between them. The Statgraphics 4.0 statistical software programme was used.

3. RESULTS

3.1. Survival

End survival after 5 years showed considerable differences between the two study species (Tab. II). Aleppo pine survival was over 90% in most of the soil preparations and Holm oak survival was 40–60%. The lowest Aleppo pines survival occurred in the areal soil preparation using agricultural techniques. It was also the only one that presented significant differences when compared to the other treatments. These results may have been caused by water loss due to high evaporation rates in the soil, given the direct insolation over the entire area. The tested soil preparations had much less of an impact on the survival of the Aleppo pine survival than on the Holm oaks. For the latter, soil preparations using backhoes for pit planting, with or without microbasins, and linear rippering allowed the plant to be more rapidly and effectively placed, ensuring its long-term survival.

However, it would be more appropriate to interpret the impact of the different soil preparations by studying the evolution of survival over time (Tab. III). In this sense, when a plantation is being set up, there are many studies [10, 11] that show the undeniable role survival plays during the first year after transplantation. In general, the highest mortality rates for the two species were recorded during this stage. The first peak in the mortality rate occurred during the first summer of the plantation (Fig. 3), which seems to indicate that summer droughts were the principal agents of seedling death. In both species, one year after planting, the only soil preparation that presented statistically significant differences in relation to the test treatments was the areal preparation. After the first year, survival during the sample period showed several tendencies (Fig. 4) that evidenced each species' ability to withstand periods of unfavorable ecological conditions. In particular, from 1998 onwards, a severe period of drought caused a high mortality rate in the Holm oak, which worsened during 1999 when annual precipitation dropped to 114 mm. To the contrary, this

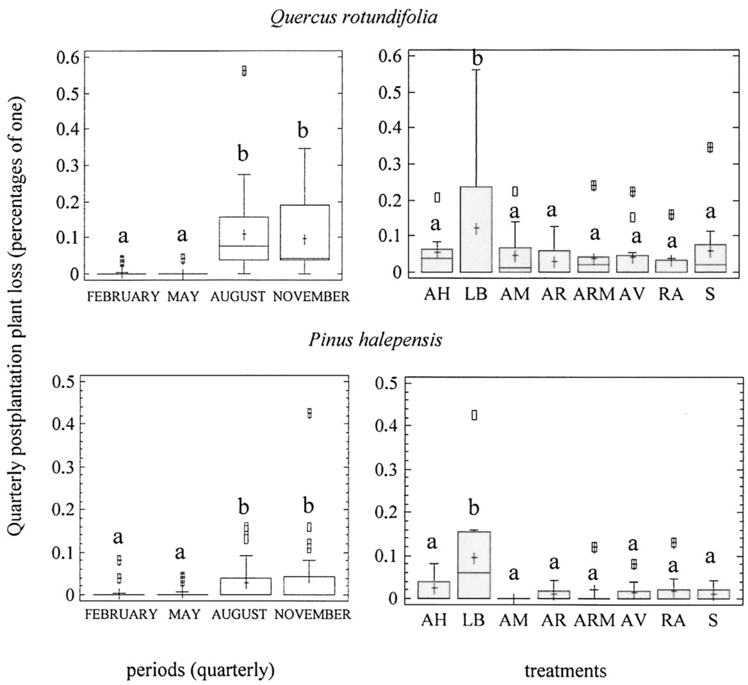

Figure 3. Significant statistical differences between quarterly dead seedling rate recorded during the first year of plantation for Aleppo pine (*Pinus halepensis*) and Holm oak (*Quercus rotundifolia*) in relation to time (three-month periods) and type of treatment. Tuckey's HSD test for multiple comparisons was used in post hoc analysis tests carried out a posteriori. Letters indicate significant differences at a confidence level of 95%.

Table III. Analysis of the variance (ANOVA of two factors: treatments and time) for the mortality rates of Aleppo pine (*Pinus halepensis*) and Holm oak (*Quercus rotundifolia*) registered during the first year after planting (in three month periods) and for the annual rates recorded during the entire monitoring period (time in years). (* $0.05 > P > 0.01$; ** $0.01 > P > 0.001$; *** $P < 0.001$.)

	Sum of squares	Df	Mean square	*F*-ratio	*P*-value
Quercus rotundifolia					
Firts year plant loss					
Periods (quarterly)	0.2543	3	0.0847	15.89	0.0000***
Treatments	0.0755	7	0.0107	2.02	0.0656
Periods x treatments	0.1513	21	0.0072	1.35	0.1785
Annual plant loss					
Periods (year)	0.601	4	0.15	22.17	0.0000***
Treatments	0.0673	7	0.0096	1.42	0.2090
Periods × treatments	0.431	28	0.0154	2.28	0.0023**
Pinus halepensis					
Firts year plant loss					
Periods (quarterly)	0.0338	3	0.0112	8.50	0.001***
Treatments	0.0737	7	0.0105	7.94	0.000***
Periods × treatments	0.1177	21	0.0056	4.22	0.000***
Annual plant loss					
Periods (year)	0.088	4	0.022	18.54	0.000***
Treatments	0.0614	7	0.0087	7.40	0.000***
Periods × treatments	0.1318	28	0.047	3.97	0.000***

long dry period had no impact on the Aleppo pine and after 1997 no further plant deaths were recorded for this species.

3.2. Species growth

The analysis of the variance for each variable according to the type of soil preparation applied (Tab. IV) showed highly significant differences ($p < 0.000$) for the mean height of the Aleppo pines, while there were almost no differences in the Holm oak for the same variable ($p = 0.07$). For the basal diameter, several differences were obtained for the Aleppo pine and the Holm oak ($p = 0.001$; $p = 0.004$, respectively).

As for the mean annual increase in height, the *p*-values obtained ($p < 0.000$) with the analysis of the variance (Tab. V)

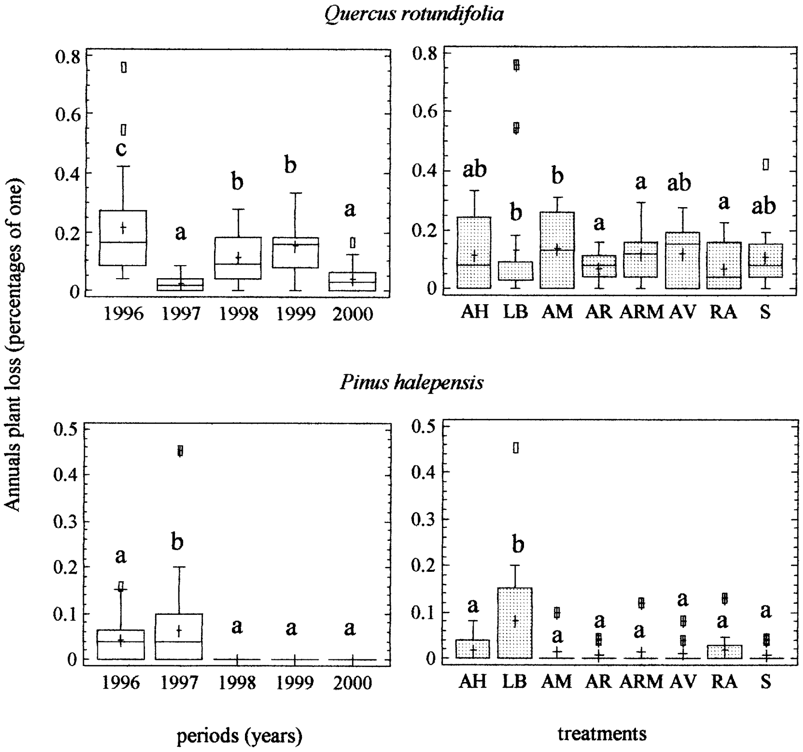

Figure 4. Significant statistical differences between the percentage of annual dead seedlings recorded during the study period (1996–2000) for Aleppo pine (*Pinus halepensis*) and Holm oak (*Quercus rotundifolia*) in relation to time (in years) and type of treatment. Tuckey's HSD test for multiple comparisons was used in analysis tests carried out a posteriori (post hoc). Letters indicate significant differences at a confidence level of 95%.

Table IV. Mean values for height (cm) and diameter (mm) of Aleppo pine (*Pinus halepensis*) and Holm oak (*Quercus rotundifolia*), 5 years after planting, in relation to each soil preparation. In one column, the numerical values followed by a letter (a, b, c, d, e) show significant differences ($P < 0.05$).

Treatments	*Quercus rotundifolia*		*Pinus halepensis*	
	Mean height ± SE (cm)	Mean diameter ± SE (mm)	Mean height ± SE (cm)	Mean diameter ± SE (mm)
Auger pit opening	25.0 ± 3.7	6.3 ± 0.1 a	140.8 ± 6.2 a	47.5 ± 2.4 ab
Mechanized subsoiling	35.1 ± 3.5	8.9 ± 0.9 ab	142.3 ± 5.8 a	40.6 ± 2.1 a
Backhoe subsoiling	41.1 ± 3.3	11.6 ± 0.9 b	184.9 ± 7.8 bc	63.9 ± 3.0 cde
Backhoe subsoiling with microbasins	36.8 ± 4.8	9.1 ± 1.4 ab	199.1 ± 6.6 c	68.09 ± 2.5 de
Ridges	39.8 ± 5.3	9.9 ± 1.5 ab	177.9 ± 7.8 bc	58.2 ± 3.0 bcd
Linear rippering with ridges	30.6 ± 3.3	8.2 ± 0.9 ab	211.1 ± 6.7 c	72.9 ± 2.5 e
Linear rippering	24.9 ± 4.4	8.2 ± 1.2 ab	157.1 ± 6.0 ab	49.3 ± 2.3 ab
Ploughing	30.7 ± 5.3	7.6 ± 1.5 ab	165.3 ± 6.6 ab	56.4 ± 2.5 bc
test	$p = 0.07$	$p = 0.004$	$p = 0.000$	$p = 0.01$

lead to the conclusion that significant differences exist in mean height increase over time for both species.

For the mean increase in basal diameter, the response of both species was very similar. Time and the types of treatment both showed significant differences, although this variable was less noticeable in the Holm oak in relation to the type of treatment ($p = 0.02$).

Figure 5 shows a diagram of the confidence intervals for the means belonging to the results obtained from Tuckey's test for multiple comparisons. They show a very similar tendency in the average annual height of both species, while the response of the basal diameter is completely different.

4. DISCUSSION

In Mediterranean territories located in ombroclimatic transition between dry and semi-arid, species with ecological requirements as diverse as those of the Aleppo pine and the Holm oak can coexist, although the oak is less resilient and its reforestation will be more difficult. The Aleppo pine will be

Table V. Analysis of the variance (ANOVA of two factors: treatments and time) for the annual increase in height and diameter in Aleppo pine (*Pinus halepensis*) and Holm oak (*Quercus rotundifolia*) recorded during the entire monitoring period (time in years). (* 0.05 > P > 0.01; ** 0.01 > P > 0.001; *** P < 0.001.)

	Sum of squares	Df	Mean square	F-ratio	P-value
Quercus rotundifolia					
Increase in height					
Periods (years)	175.391	3	212.389	12.22	0.0000***
Treatments	637.167	7	25.0559	1.44	0.2044
Periods × treatments	370.715	21	17.6531	1.02	0.4585
Increase in diameter					
Periods (years)	18.632	3	6.2109	7.16	0.0003***
Treatments	15.267	7	2.1810	2.51	0.0239*
Periods × treatments	17.792	21	0.84.72	0.98	0.5019
Pinus halepensis					
Increase in height					
Periods (years)	12455.9	3	4151.98	100.57	0.0000***
Treatments	1830.08	7	261.44	6.33	0.0000***
Periods × treatments	1151.87	21	54.851	1.33	0.1916
Increase in diameter					
Periods (years)	2614.23	3	871.409	169.34	0.0000***
Treatments	302.991	7	43.284	8.41	0.0000***
Periods × treatments	228.031	21	10.858	2.11	0.0118*

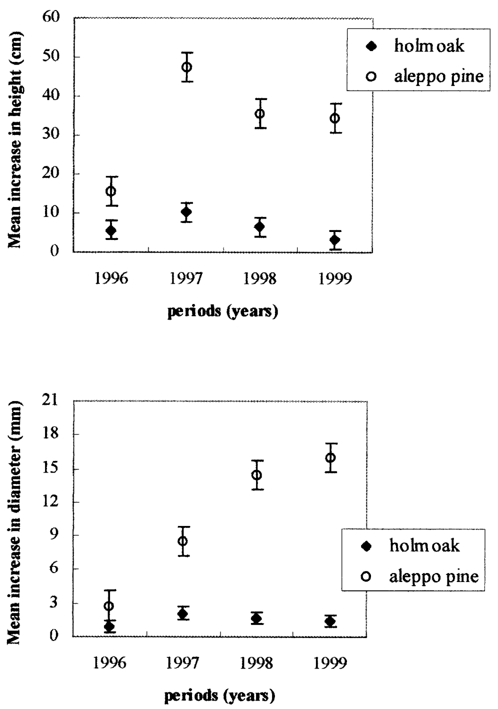

Figure 5. Evolution of the annual mean increase in height and diameter (mean ± confidence interval) registered during the study period (1996–2000) for Aleppo pine (*Pinus halepensis*) and Holm oak (*Quercus rotundifolia*) and statistically significant changes in mean increases in height and diameter of Aleppo pine (*Pinus halepensis*) in relation to the treatments tested at a level of significance of 95%.

developing in an optimal ecological environment while the Holm oak will be in an extreme situation due to its arid ecological distribution, even though it will only be found in the more microtopographically humid areas (e.g. northern watersheds, in foothills or depressions). Under these conditions, although the oak is very flexible, the slightest change in environmental conditions can become adverse [7]. The tree is especially sensitive to unusual ecological conditions during the adaptive stage that follows reforestation. A period of extreme dryness, such as the drought recorded during the last three years of this experiment, was enough to cause massive mortality among the Holm oaks belonging to the forestation experiment in Rambla de Becerra. Their growth was reduced and even anulled during that period.

In dry and semi-arid Mediterranean territories, lack of water is the most limiting factor for reconstructing ecosystems [16]. Therefore, it is essential for seedlings to develop a root system as quickly as possible to escape from soil desecation [4, 12, 15], especially during the first summer after planting. Plantation success also depends on this.

This factor's impact can be partly mitigated by applying soil preparation techniques that improve the land's soil conditions and water availability, and accelerate root growth. This is demonstrated by the outcomes analysis and the correlation of the behaviour indexes for the height and diameter of the Holm oak and Aleppo pine. It was seen that there are two clearly differentiated groups of soil preparations depending on their impact on Holm oak and Aleppo pine establishment and development (Fig. 6). In this sense, the most effective preparations are those that offer the seedlings the highest volume of useful soil for their root system and the highest water storage capacity. An

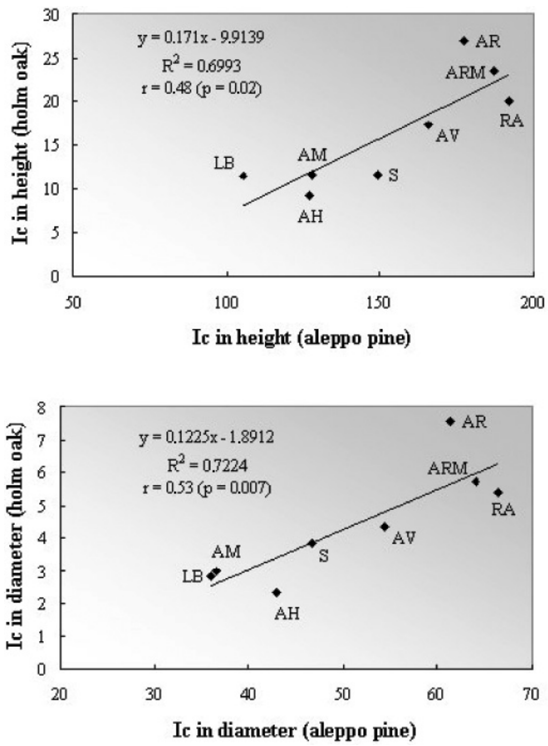

Figure 6. The relation between the behaviour indexes of the two variables studied for Holm oak (*Quercus rotundifolia*) and Aleppo pine (*Pinus halepensis*) (r = correlation coefficient; R^2 = regression coefficient).

example of these effective soil preparations would be those that use backhoes for pit planting and linear rippering. In any case, it is worth mentioning the enormous impact of the hydraulic structures associated with these rippering preparations.

Finally, areal soil preparation is not recommended, especially in Holm oak forestations. It causes extremally high plant loss and makes the plantation fail, a risk that managers cannot assume.

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