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Short-term effect of early thinning on growth in stone pine in Tunisia

Effet à court terme d'une éclaircie précoce sur la croissance de Pin pignon en Tunisie

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Abstract – The aim of this study was to quantify growth responses of 14-year-old artificially regenerated stone pine (*Pinus pinea* L.) stands to thinning in Northwestern Tunisia, four years after treatment. The study included four thinning intensities (light (17% of trees was removed), moderate (40% of trees was removed), strong (63% of trees was removed) and very strong (81% of trees was removed) thinning), plus control (0% of trees was removed) replicated in four randomized block design. The variables measured included height growth, diameter at breast height (dbh), crown radius, branch diameter of the whorl closest to breast height (1.3 m), length and dry mass of needles, and soil water content. Thinning led to an increase in dbh between 3 and 35%, while there was no significant effect on height growth. Thinning also promoted crown expansion and branch diameter, whereas no effects on length and dry mass of needles were found. On the other hand, there were no differences among treated and untreated plots with regard to soil water content. Thus, changes in tree growth tend to be linked most closely to increases in space and light availability in the thinned plots.

Keywords: thinning; *Pinus pinea* L.; growth

Résumé - L'objectif de la présente étude est de quantifier la réponse de croissance d'un peuplement jeune (14 ans) de Pin pignon (*Pinus pinea* L.), régénéré artificiellement, à l'éclaircie. Quatre intensités d'éclaircie (faible (en enlevant 17% des arbres), modérée (en enlevant 40% des arbres), forte (en enlevant 63% des arbres) et très forte (en enlevant 81% des arbres)) en plus d'un témoin (non touché), répétés en quatre blocs randomisés, ont été ainsi appliqués. L'étude a été menée, durant 4 ans (1994-1998), au Nord-Ouest de la Tunisie. Les mesures réalisées ont porté sur la croissance en hauteur, le diamètre à la hauteur de poitrine (1,3 m), le rayon du houppier, le diamètre des branches du verticille le plus proche de 1,3 m, la longueur et la biomasse sèche des aiguilles ainsi que le bilan hydrique. Quatre ans après l'éclaircie, le diamètre des arbres a augmenté de 3 à 35%, alors que le changement en hauteur a été insignifiant. L'effet de l'éclaircie s'est traduit également par une augmentation de la largeur du houppier et du diamètre des branches. En revanche, aucun effet significatif sur la croissance en longueur ou en biomasse des aiguilles n'a été trouvé. L'éclaircie n'a pas eu d'effet significatif aussi sur le bilan hydrique, et les changements de croissance notés semblent être donc étroitement liés à l'augmentation de l'espace et de la disponibilité de la lumière autour des arbres des parcelles traitées.

Mots clés : éclaircie ; *Pinus pinea* L. ; croissance

1. Introduction

Stone pine (Pinus pinea L.) is a species native to the Mediterranean area, where it covers more than 700,000 ha (Mutke et al. 2012), mainly in Spain (450,000 ha), Portugal (90,000 ha), Turkey (50,000 ha) and Italy (40,000 ha) (Pereira et al. 2015). It was successfully introduced in Tunisia more than a century ago (1907) being used primarily, along the Mediterranean coast line, to consolidate the coastal dunes of Bizerte in the North and along the North East coast in the region of Cap Bon (Hasnaoui 2000). The success of these first plantations incited the foresters to use this species to stabilize the coastal dunes of the Northwest too. Today, Pinus pinea occupies an area of 21,165 ha (El Khorchani 2010) and becomes one of the most valuable species in Tunisian reforestation programs due to its usefulness for both wood and fruit production (pine nuts) and its ability to grow in dry and sandy soils. These stone pine forests suffer, however, a lack of silvicultural interventions that can potentially aid in improving their growing conditions.

Thinning is the most commonly applied silvicultural treatment, thus it has received considerable attention in forest research. Thinning has traditionally been used to increase tree growth or improve its quality on a sustainable basis (e.g. Houtzagers 2002; Tullus 2002; Zeide 2004). After thinning, remaining trees can use the released resources, such as light, water and nutrients, to expand their crowns and to grow faster in diameter (Mäkinen and Isomäki 2004a; González-Ochoa et al. 2004; Crecente-Campo et al. 2009; Pérez-de-Lis et al. 2011). When properly used, thinning reduces long-term stress by competition, but it also reduces the vulnerability of trees to extreme drought events (Linares et al. 2011; Sánchez-Salguero et al. 2012). However, the advantages of thinning for growth may not be the same for trees of different species (Moreno-Fernández et al. 2014; Navarro-Cerrillo et al. 2016) depending on their shade tolerance (Navarro-Cerrillo et al. 2016).

In the Mediterranean basin, several thinning experiments have been carried out in other pines (e.g. Del Río et al. 2008; Montero et al. 2001; Navarro-Cerrillo et al. 2016). However, there is much less information about the effect of thinning on stone pine (Gordo et al. 2009), which contrasts with the utility of the species. Thus, the main objective of this study was to analyze the effects of thinning on the growth of a 14-years-old artificially regenerated stone pine stand, four years after treatment application.

2. Matériel et méthodes

2.1. Study area and vegetal material

The study was carried out between 1994 and 1998, on a14-years-old low pole stone pine stand, at the plot 8 of the first serial of Mekna I (36°57′3.88″N, 8°48′49.98″E, 48 m a.s.l) in Northwestern Tunisia. The plot area has5 ha, and was occupied by eucalyptus until 1980, when it was substitute with a stone pine plantation. The climate is Mediterranean with an annual mean temperature of 17.9°C (1900 - 1988) (Hasnaoui 1992). Absolute maximum and minimum temperatures are 47°C (August) and -1°C (January), respectively (Hasnaoui 1992). The average annual rainfall is 1013 mm, with 46% of the total rainfall falling in winter, 24% in spring, 3% in summer and 27% in autumn.

2.2. Experimental design and treatments

The experiment was arranged as a randomized complete block with four replications (or blocks). The thinning treatments, in each block, were carried out on five experimental plots: control plot (0% of trees was removed); plot with light thinning where 17% of trees was removed; plot with moderate thinning where 40% of trees was removed; plot with strong thinning where 63% of trees was removed, and plot with very strong thinning where 81% of trees was removed. Each treatment was applied in one 400 m^2 plot. Thinning treatments were carried out in 1994, and removed trees were trees with smaller diameters and tree forks.

2.3. Measurements

Tree height, diameter at breast height (dbh) and crown radius were measured just after thinning (1994). They were recorded again at the end of the experiment (1998) along with tree density (number of remaining trees per treatment after thinning), branch diameter and soil water content. Measurements of diameter were systematically made, by keeping the same direction of measurement as well as the same height (1.30 m). Ten trees of a mean arithmetical diameter were selected from each treatment for height measurements. Measurements were made using a ranging rod. When height exceeds 6 meters we use the Blume Leiss. On the 10 trees previously selected, we measured three radii of the crown by

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projection on the soil. These radii were spaced of 120° approximately, and the average radius was calculated. Branch diameter was measured in the first whorl closest to the breast height (1.3 m). The average branch diameter was obtained by dividing the sum of the branch diameters by the number of branches. On the same selected trees, 30 needles (3 needles per tree) aged two years old (1996-1998) were removed and measured for their length. Fresh and dry needle (at 60°C for 48 hours) weight was calculated. To appreciate the water conditions of the experimental plot, four samples of soil per treatment were taken, in spring 1998, at 40 cm depth. They were then mixed to make a composite sample in each plot (or treatment). This volume was weighed in a fresh state then in a dry state after drying at 100°C for 48 hours to determine the soil moisture rate.

2.4. Data analysis

Data were analyzed using the Statistical Analysis System (SAS Institute Inc., Cary, NC), corresponding to the following general linear model (Anon 1998):

$$Y_{ij} = \mu + A_i + B_j + e_{ij}$$

Where Y_{ij} = the independent variable; μ = general mean; A_i = effects of block; B_j = effects of thinning treatments and e_{ij} = error term.
For each analysis, when the analysis of variance was significant, statistically significant differences between means were identified using Waller-Duncan K-ratio = 100 (Little and Hill 1978). Differences were considered significant at $P \leq 0.05$. Finally, all measured parameters were used to make an analysis of the correlation by using the test of Pearson correlation.

3. Results and discussion

3.1. Tree characteristics at establishment of the experiment

At the beginning of the experiment, just after thinning (1994), height, diameter at breast height (dbh), and crown radius of trees were similar between thinning treatments (Table 1). By contrast, significant differences in tree density between thinning treatments were found. Hence, any future change in trees growth between thinning treatments from then on would be interpreted as it is due to the thinning operation.

Table 1. Analysis of variance (Pr>F) and mean values of tree density, diameter at breast height (1.3 m), tree height and crown radius, just after thinning application (1994).

Treatments	Control	Light	Moderate	strong	Very strong	Pr>F
Variables						
Density (number of trees/treatment)	82.7a	68.6b	49.4c	30.3d	15.7e	<0.0001*
Diameter at 1.3 m (cm)	11.2a	10.1a	10.8a	11.1a	10.4a	1.1460
Tree height (m)	5.0a	5.2a	5.3a	5.3a	5.4a	1.1340
Crown radius (m)	1.3a	1.5a	1.6a	1.6a	1.5a	1.0713

For a same line, *P* values marked with an asterisk (*) indicate the presence of a significant thinning effect, while mean values marked with different letters indicate the presence of a significant difference at $P \leq 0.05$ level.

3.2. Radial growth

Studies on the effect of thinning in diameter growth of residual trees are numerous for many tree species from a wide geographical range. These studies demonstrated that thinning promotes dbh of many species of both conifer and hardwood trees (Briggs and Lemin 1994; Burns et al. 1996; Varmola et al. 2004; Medhurst et al. 2001; Juodvalkis et al. 2005; Rytter and Werner 2007). This is in agreement with the results of our work which show that thinning favored diameter growth; the trees which initially (just after thinning, 1994) had no significant differences in diameter at breast height (dbh) showed after four years of growth (1998) statistically significant differences between thinning treatments, and average dbh was greater for thinned than for unthinned (control) plots by 3% (0.4 cm), 10% (1.3 cm), 17% (2.2 cm), 35% (4.4 cm), respectively under light, moderate, strong and very strong thinning (Table 2). Differences were, however, significant only for strong and very strong intensities of thinning indicating that thinning effect is influenced by thinning intensity. On the other hand, while both of these thinning regimes resulted in a significantly increase in diameter growth this diameter was significantly greater under very strong than under strong thinning. This is in line with other results obtained in many studies carried out in central and northern Europe which establish that thinning intensity must be high (e.g. Mäkinen and Isomäki 2004b). It has been shown recently, however, that responses of tree species to thinning depend on their shade tolerance; for instance, Pinus sylvestris showed a significantly higher radial growth under light thinning intensity, while Pinus pinaster which it is less tolerant to shade showed a significantly higher radial growth under heavy thinning (Navarro-Cerrillo et al. 2016). P. pinea is reputed to be a very light-demanding species (Adili 2012), which could explain why radial growth reached its maximum under very strong thinning regime.

3.3. Tree height and needles growth

Contrary to trees diameter, height was unaffected by thinning intensity (Table 2). Similar results were found in various broad-leaved (Graham 1998; Medhurst et al. 2001; Rytter and Werner 2007; Çiçeket al. 2013; Diaconu et al. 2015) or coniferous (Del Río et al. 2008; Mäkinen and Isomäki 2004b; Crecente-Campo et al. 2009) species. It was reported that stand density has significant effects on diameter growth but not on height growth, except for very high and very low stand densities (Çiçeket al. 2013). In our study thinning did not affect height growth, meaning that tree densities are at a level that does not affect trees height. On the other hand, it has been also reported since long that the carbon allocation for height growth is more primary than the carbon allocation for diameter growth (Lanner 1985) which may also explain why thinning did not affect height growth. As shown in table 2, there were also no significant differences between thinned and unthinned plots neither for length nor for the dry mass of needles. It is known, in general, that morphological needle parameters increase with increasing tree height (Gebaueret al. 2011) reason for which perhaps both length and dry mass of needles, as found for height growth, was independent of thinning treatments.

3.4. Branch diameter

It is well known that tree branches result in knots within the stem, which reduces strength because of changes in fibre angles and interruption of wood continuity as growth rings of branches join growth rings of the stems (Raprager 1939; Green et al. 1999). In addition, compression wood is formed at the base of branches via adaptive responses that increase support for them (Schultz 1997). Both of these traits negatively influence wood quality, especially on strength and shrinkage parameters (Perstorper et al. 2001). Similar to other studies (e.g. Varmola and Salminen 2004; Fahlvik et al. 2005), our study showed that the mean branch diameter of the whorls closest to breast height tended to increase with increasing thinning intensity (Table 2). The result is, therefore, increased diameter knots within the stem. Accordingly, retention of branches on the stem after thinning, and especially under very strong thinning regime where branch diameter was found to be significantly increased compared to unthinned control plots as our results show, is not recommended when thinning is oriented towards the production of high-quality timber.

3.5. Crown projection and soil water content

Juodvalkis et al. (2005) showed that a very significant rise in the increase of crown volume can be achieved through thinning in the case of young trees – for example, those aged 10–20 years in the case of pines. This may be confirmed in our study for stone pine, where thinning was found to increase crown radius, on average, by 11 to 28% although the difference under light thinning was not significant compared to unthinned control plots (Table 2). Crown width expansion in remaining trees suggests that trees tended to maximize their space and light interception. It was found, on the other hand, for the same species that tree-level cone production is positively related to diameter and crown width (Calama et al. 2008; Gonçalves and Pommerening 2012). So when the management goal is fruit production, thinning can be done to increase crown growth which will also increase fruit production. Based on the results obtained for crown and diameter growths we can establish that trees had a higher dbh increase (there was a significant increase in dbh under very strong thinning regime compared to strong thinning regime) rather than crown width increase (there were no significant differences between moderate, strong and very strong thinning regimes (see table 2)). This is because trees, as reported by Loewe et al. (2013) seem to devote their resources to consolidate first, and later to a greater fruit production. It is interestingly to emphasize, on the other hand, that increased crown growth under moderate thinning and its stabilization since, suggest that this thinning regime is largely sufficient to stimulate crown development, when the forest objective is the fruit production, which may help to minimize the cost of the thinning operation comparatively to strong and very strong thinning regimes.

Several thinning studies have reported that in Mediterranean sites, thinning could enhance tree growth by improving the tree water status (Bréda et al. 1995; Ma et al. 2010; Molina and Del Campo 2012), since tree growth is usually mainly limited by water deficit (Sabaté et al. 2002). However, more recently Primicia et al. (2016) found that soil moisture was higher in unthinned than in thinned plots even 9 years after the first thinning. In our study plots we did not observe also, after four years, that thinning increases soil moisture and differences between treatments were not significant (Table 2). These contrasting results indicate that thinning does not guarantee the improvement of water availability in thinned plots. Finally, it should be underlined that the absence of a soil water content effect of thinning found in this study could indicate that in thinned plots *i*) low tree density make better use of available water (by expanding roots) and *ii*) there was an increase of evapotranspiration.

Table 2. Analysis of variance (Pr>F) and mean values of diameter at breast height (dbh), tree height, branch diameter, crown radius, length and dry mass of needles and soil water content under different thinning intensities: control, light thinning intensity, moderate thinning intensity, strong thinning intensity and very strong thinning intensity.

Treatments	Control	light	moderate	strong	Very strong	Pr> F
Variables						
dbh (cm)	12.6a	13.0a	13.9ab	14.8b	17.1c	<0.0001*
Tree height (m)	6.3a	6.8a	7.0a	6.8a	6.6a	0.7010
Branch diameter (cm)	3.5a	3.6a	3.8a	3.8a	4.7b	0.0400*
Crown radius (m)	1.6a	1.8ab	1.9bc	1.9bc	2.1c	0.0180*
Needles length (cm)	9.1a	8.7a	8.7a	8.6a	9.3a	0.5713
Dry mass of needles (g)	0.695a	0.713a	0.704a	0.717a	0.905a	0.4950
Soil water content (%)	2.7a	3.3a	3.4a	3.1a	3.0a	0.7806

For a same line, *P* values marked with an asterisk (*) indicate the presence of a significant thinning effect, while mean values marked with different letters indicate the presence of a significant difference at $P \leq 0.05$ level.

3.6. Correlation between variables

The correlation analysis, presented in table 3, clearly demonstrates that the growth traits significantly affected by thinning (dbh, crown projection, branch diameter) were significantly correlated with tree density, which was not the case for those growth traits that were independent of thinning effect (height growth, length and mass of needles). These results support the general idea that tree growth is regulated by thinning by controlling stand density (Mäkinen and Isomäki 2004a). For the same species (Pinus pinea L.), diameter growth was found to be positively correlated with crown size (Ciancio et al. 1986). However, in our study we did not find that crown expansion is correlated with diameter growth; hence, the larger trees, the larger crown seems to be not the case in this study, and crown width seems to be more proportional to tree height than to tree diameter, as it significantly and positively correlated with height growth. Irrespective of its correlation with tree density, branch diameter was found to be significantly and positively correlated with dbh which is in agreement with the results documented by other researchers for other coniferous species (e.g. Persson 1977 for Scot pine; Pfister 2007 for Norway spruce; Liziniewicz 2014 for Norway spruce, Scots pine, Lodgepole pine). Finally, it should be underlined that the dependence of needle morphology on height growth, as previously mentioned, may be confirmed but only for needle length which was found to be significantly correlated with tree height; needle mass was not correlated with tree height, but rather with needle length.

Table 3. Pearson's correlation (R^2) between different variables, with T.D = tree density, dbh = diameter at breast height (1.3 m), H = tree height, B.D = branch diameter, C.R = crown radius, N.L = needle length, N.M = needles mass.

	T.D	dbh	H	B.D	C.R	N.L	N.M
T.D (trees/plots)	1						
dbh	-0.55*	1					
H	-0.05	0.13	1				
B.D	-0.24*	0.43*	-0.08	1			
C.R	-0.24*	0.13	0.24*	0.23*	1		
N.L	0.09	0.10	0.15*	0.11	0.16*	1	
N.M	-0.10	0.24*	-0.14	0.41*	0.01	0.59*	1

Values marked with an asterisk (*) indicate the presence of a significant correlation at $P \leq 0.05$ level.

4. Conclusion

The results from our study show that thinning may have a positive effect on growth of young stone regenerated artificially pine stands. This effect was, however, dependent on thinning intensity. Thus, trees started to react significantly under moderate thinning regime for crown expansion, under strong thinning regime for dbh, and under very strong thinning regime for branch diameter. These observed growth changes under thinning seemed to be not linked to soil moisture, which was not improved after thinning, but rather to increase in the available space surrounding trees and the amount of intercepted light. It is known that tree branches become knots within the stem. Thus, retention of branches on the stem under very strong thinning, where there was a significant increase in diameter of these branches, may result in increases in both the abundance and size of knots. However, knots within the stem constitute a defect when the tree is assessed for timber quality and when the tree is processed into boards. In this case, early prunings under very strong thinning are therefore required. Contrary to diameter growth, thinning did not lead to an increase in height growth. Thus, when we consider the height growth as an index of site quality one can draw the conclusion that there were no differences in the fertility of different plots, and that thinning did not create therefore fertility classes. In general, our results allows to gain important knowledge about the effects of different thinning regimes in stone pine forests, which will contribute to improve stone pine forest management.

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