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Survival and early growth of mixed forest stands installed in a Mediterranean Region: Effects of site preparation intensity

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ABSTRACT

In Mediterranean environments, availability of water and nutrients are the main factors limiting the success of afforestation. As part of a wider project, an experiment was established in Northeast Portugal, aiming at testing the effect of several site preparation techniques on plant survival and growth (height and diameter) in a newly installed mixed forest stand. Results presented regard plant response during 42 months after plantation. The experimental protocol consisted in seven treatments described by mechanical operations that rank soil disturbance intensity from none to high, set in plots of 375 m^2, randomly distributed in three blocks, in different topographic positions (gentle slope plateau, moderate slope shoulder, and steep mid-slope). *Pseudotsuga menziesii* (*PM*) and *Castanea sativa* (*CS*) forest species were planted in a 4 m × 2 m scheme and in alternate rows with 12 plants on each row per plot, summing up 72 plant per specie and treatment at start of the experiment. The results show that: (i) the highest mortality was observed immediately after the plantation and before the dry season, on the lowest intensity treatments; (ii) after the dry season, the highest mortality was also observed in treatments with the lowest intensity of soil disturbance, while the lowest values were found on the intermediate intensity treatments; (iii) during the experimental period, the effect of treatments on plant growth (height and diameter) was statistically significant; however, experimental results do not lead yet to a clear quantitative relationship between soil disturbance intensity due to site preparation and plant response under the conditions tested.

1. Introduction

In Mediterranean environments, availability of water and nutrients are the main factors limiting the success of afforestation (Daget, 1977; Rey, 1998; Ojasvi et al., 1999; Bocio et al., 2004). Afforestation programmes in Portugal have to take into account these soil and climatic constraints, as Mediterranean climate prevails in most of the territory (Ribeiro, 1986; Costa et al., 1998). In Portugal the success and productivity of most forest plantations is limited by poor soil conditions, namely a low root support capacity, which has negative effects on the amount of available water and nutrients. Soil preparation operations are therefore required before planting, using more or less intense tillage in order to increase soil depth, as well as water and nutrient availability, and, so, improving soil conditions for plant growth (Worrell and Hampson, 1997; Fisher and Binkley, 2000; Querejeta et al., 2001).

Several studies have been made on the effect of surface soil tillage using scarification and herbicide application for weeds and shrub control and improving root depth (McLaughlin et al., 2000; Archibold et al., 2000; Burgess and Wetzel, 2000; Wetzel and Burgess, 2001). However, there are only few references on the effect of deep tillage on soil properties and plant response (Fernandes and Fernandes, 1998; Fisher and Binkley, 2000; Querejeta et al., 2001; Martins and Pinto, 2004; Carlson et al., 2006). New studies are therefore necessary to improve our knowledge and to support decisions on best operation selection according to site conditions. The wide diversity of mechanical site preparation techniques that may be applied emphasizes the need for studies on newly installed forest stands, especially in areas where information is still limited, as it is particularly the case of the Mediterranean Region (Varelides and Kritikos, 1995). Furthermore, most studies are performed in adult stands, and so the installation phase is less understood, often lacking important components of the initial dynamics of these systems (Canham, 1989; Lieberman et al., 1989).

This paper aims at presenting and discussing data collected 42 months after plantation in an experiment carried out to study mortality and growth (height and diameter) of a mixed stand of

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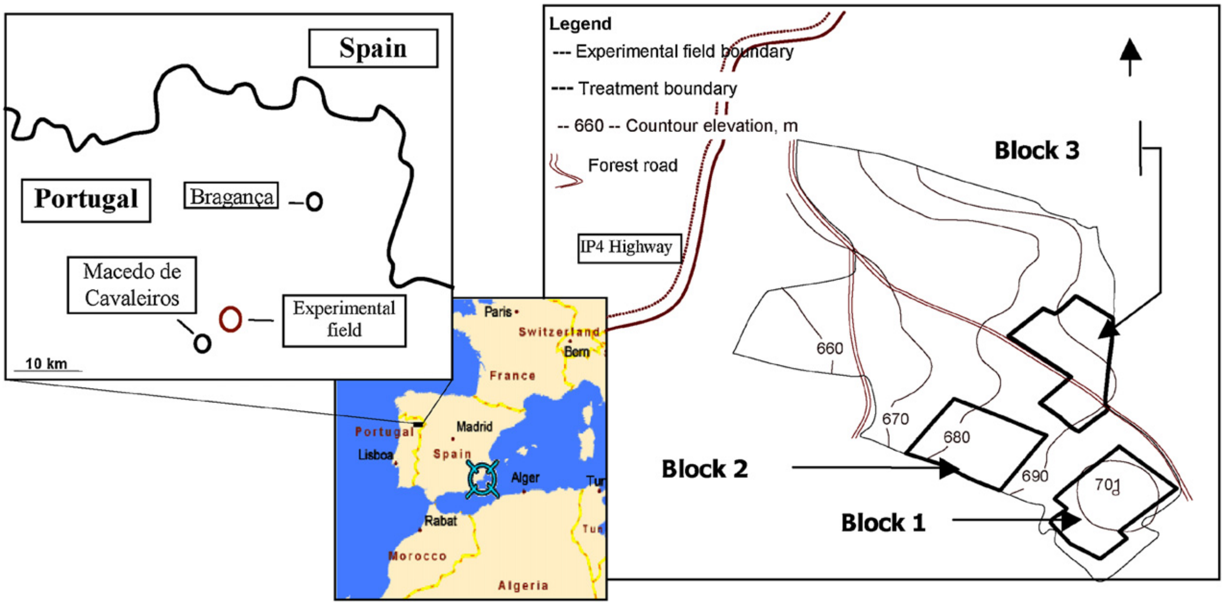

Fig. 1. Study area location.

Pseudotsuga menziesii and *Castanea sativa*, as affected by different mechanical operations performed for soil preparation.

2. Materials and methods

The experimental field was established near the municipality of Macedo de Cavaleiros, Northeast Portugal, at 41°35′N and 6°57′W, local altitude ranging from 660 to 701 m (Fig. 1). Climate is Mediterranean, with 12 °C mean annual temperature and 678 mm mean annual rainfall at Macedo de Cavaleiros (INMG, 1991). During the experimental period, annual rainfall was 665 mm, monthly distributed according to Fig. 2, averages being computed from data recorded by an automatic rain gauge installed in the experimental site.

The experimental design consisted of six treatments representing different intensities of soil disturbance by mechanical operations for site preparation, randomly distributed on each one of three blocks, which cover the range of soil and topographic conditions commonly found in afforested areas in NE Portugal (Agroconsultores and Coba, 1991), described as follows: Block 1 on a gentle slope plateau (6% slope gradient), over sedimentary parent material Dystric Cambisols; Block 2 on a moderate slope shoulder (12%); and Block 3 on a steep slope (22%). Blocks 2 and 3 were installed in neighbouring west facing hillslopes, over schists, Dystric Leptosols (FAO/UNESCO, 1987; Agroconsultores and Coba, 1991). The treatments, described in Table 1, ranked from lowest (SMPC) to highest (RCLC) soil disturbance, induced by different soil preparation operations. Table 1 includes also a treatment without disturbance (TSMO), which corresponds to the original soil and is taken as a reference for comparison with the remainder treatments in what concerns the tillage effects on soil properties. Soil characteristics of experimental area prior to experiment installation (represented by TSMO, Table 1) were determined in previous work by the first author (Fonseca, 2005). Accordingly, soil texture varied between loam and sandy loam (63–73% sand, 15–24% silt, 9–13% clay), effective soil depth between 50 and 55 cm, bulk density (0–15 cm) between 1.4 and 1.5, organic carbon between 14 and 33 g kg^{-1}, total nitrogen between 0.7 and 1.1 g kg^{-1}, sum of exchangeable bases between 1.3 and 2.1 cmol$_c$ kg^{-1} and pH (H_2O) between 5.0 and 5.2.

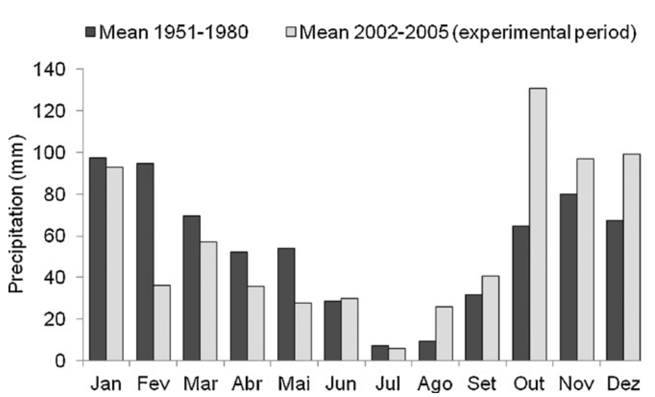

Fig. 2. Monthly average precipitation during the experimental period (2002–2005) and long term means (1951–1980).

Plots 25 m × 15 m in size (wider in contour) were taken as the experimental units in this study. A total of 21 plots were installed in the experimental field, accounting for 6 treatments plus one non planted reference in 3 blocks. The plots were separated by wide buffer belts of 3 m. The species selected were *P. menziesii* (*PM*) and *C. sativa* (*CS*), planted in alternate contour rows, in a 4 m × 2 m scheme (rows × plants in rows), each plot summing up two rows per specie, 12 plants per row in a total of 24 plants per species, and each treatment including 72 plants per species at the experiment start. The plantation was made by hand, in February 2002, using nursery seedlings, containerized in the case of *PM* and bareroot in the case of *CS*.

For the evaluation of plant response, mortality was quantified according to the percentage of dead plants in the total in each treatment, at plantation, and in May (before the dry season, bds) and in September (after the dry season, ads) of 2002, 2003, 2004 and 2005. Plant growth was quantified as height and diameter at ground level, measured on all plants of each plot, at plantation, and after 12, 24, 27, 30, 36, 39 and 42 months, corresponding to four growing seasons. In the third and fourth growing season measurements were performed to further assess spring growth (24–27 and 36–39 month periods) and summer growth (27–30 and 39–42 months). SMPC and RCAV treatments were excluded from these measurements, because most of the plants died after plantation. As

Table 1
Treatments representing the original condition and the six soil preparation operations performed before plantation.

Treatment	Description of site-preparation operations
No disturbance	
TSMO	Original condition (without plantation)
Slight disturbance	
SMPC	No tillage and hole plantation with hole digger (60 cm depth)
RCAV	Continuous subsoiling, using a covering shovel and plantation in the furrow (around 60 cm depth)
Moderate disturbance	
SRVC	No previous subsoiling with furrow hillock surface soil with two plough passes and plantation in the hillock side (around 90 cm depth)
RLVC	Subsoiling on planting row, followed by two plough passes, leaving furrow hillock surface soil and plantation in the hillock side (around 90 cm depth)
High disturbance	
RCVC	Continuous subsoiling, followed by two plough passes, leaving furrow hillock surface soil and plantation in the hillock side (around 90 cm depth)
RCLC	Continuous subsoiling followed by continuous ploughing and plantation in the furrow (around 90 cm depth)

Fig. 3. Examples of root systems observed two years after plantation, in species *CS* and *PM*.

a complement to previous measurements, observations of the root system were also made following procedures described by Fonseca et al. (2005), as illustrated in Fig. 3.

One year after planting, six soil profiles per treatment were observed in the plantation line. Soil samples were taken at 0–20, 20–40 and 40–60 cm to assess the effects of site preparation on soil properties and possible relationships with plant response. Effective soil thickness, defined as the set of layers most explored by plant roots, was measured in each profile during soil profile description. In March 2004, the soil penetration resistance was determined using a penetrologger set with a cone of 1 cm^2 and angle of 60°, to an 80 cm maximum depth, making up 30 measurements per treatment.

Statistical analysis of data comprised one-way ANOVA and multiple comparison of averages (Tukey, 5%), performed to assess the significance of treatment effects on results. Mortality data were transformed (2 arc sine $\sqrt{x}$, x being the mortality expressed as percentage of the total number of plants in each plot) prior to ANOVA (Dagnelie, 1973). Simple correlation analyses were applied to estimate and test hypothesized relationships between variables.

3. Results and discussion

3.1. Soil characteristics

Results presented in this sub-section concern soil properties associated with the two main determinants of plant survival and growth in young forest stands: (i) root expansion allowed within soil thickness, which determines access to soil-borne resources required for plant growth, as water and nutrients; (ii) fertility status in layers most relevant for soil biological activity identified by selected chemical properties in surface soil.

The soil effective thickness (rooting depth) is higher in treatments with moderate and intensive site preparation than in the remainder ones (Fig. 4). The treatments SRVC, RLVC and RCLC, when compared with the original soil (TSMO), show the greatest increase in soil depth, with increments from 30 to 40 cm along the planta-

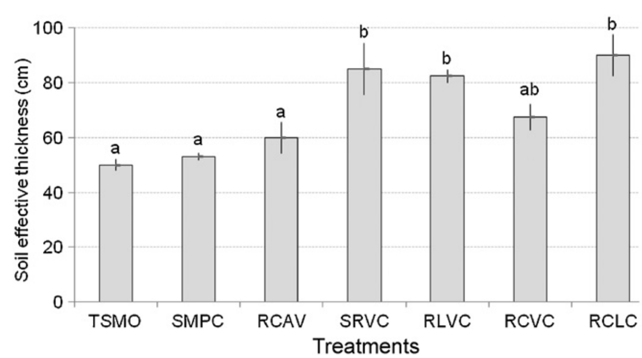

Fig. 4. Means and standart errors of soil effective thickness one year after site preparation. For treatments, averages with the same letter are not significantly different ($P < 0.05$).

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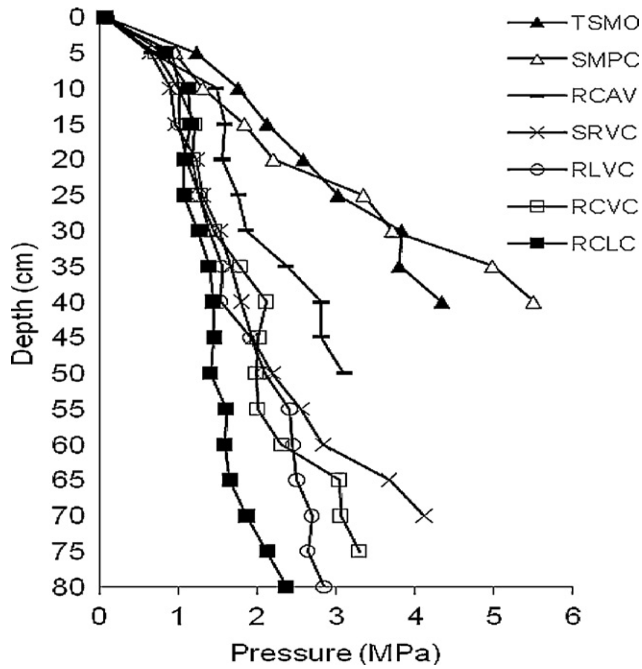

Fig. 5. Average soil penetration resistance in March 2004 (two years after site preparation), according to the treatments.

tion row. In slight soil disturbance treatments (SMPC and RCAV), this effect was hardly noticeable. Also, treatments with slight soil disturbance and the original soil (TSMO) together show the highest soil penetration resistance whereas the most intensive one (RCLC), presents the lowest among all treatments. Treatments with furrow hillock surface soil (SRVC, RLVC and RCVC) show intermediate values of soil resistance to penetration (Fig. 5). Thus, intensification of site preparation contributed to the increase of soil depth and decreased soil strength, factors that promote root expansion and development, gas exchange and water infiltration and redistribution in the profile, contributing to plantations' success. Soil penetration resistance may be an appropriate index to evaluate the influence of soil density in the distribution and development of root systems (Schoenholtz et al., 2000). Relationships between root growth and soil penetration resistance are reported by several authors (Curt et al., 2001; Abu-Hamdeh, 2003; Fonseca et al., 2005; Carlson et al., 2006; Sánchez-Andrés et al., 2006).

Values of soil organic carbon, total nitrogen, phosphorus extractable (P Olsen), sum of exchangeable bases and pH (H_2O) are depicted in Table 2. Results show that, when compared with the original soil (TSMO), soil organic carbon and total nitrogen decrease significantly in treatments with moderate and high soil disturbance (SRVC, RLVC, RCVC and RCLC), while sum of exchangeable bases increase, but only significantly in SRVC. Values of pH (H_2O) did not vary significantly with treatment (4.8–5.1).

Typically, site preparation favors the mixing of organic matter and mineral soil, which stimulates bacterial population growth and consequent mineralization of organic matter (Madeira et al., 1989; Johansson, 1994; Hussain et al., 1999; Islam and Weil, 2000), leading to loss or transfer of nutrients, particularly carbon and nitrogen (Islam and Weil, 2000; Piatek et al., 2003). The reduction in soil nutrient levels can affect the plantations success, even though this is not a factor as critical as soil moisture content and aeration (Archibold et al., 2000). In spite of the changes in carbon and nitrogen induced by site preparation techniques, Dick et al. (1998) report that the largest changes in organic matter content occur during the first five years after site preparation, with little variation beyond that period.

3.2. Species mortality

Table 3 shows that the SMPC and RCAV treatments, with less intense soil tillage, have mortality of almost 90% for both species, *PM* and *CS*. In the other treatments mortality was generally lower than 50%, especially in SRVC and RLVC, but with higher values in the case of *PM*. On the other hand, almost all the mortality occurred during the dry season after plantation (Fig. 6), which underlines the high susceptibility of recently planted species during this period, corroborating results reported in literature (e.g., Cogliastro et al., 1997; Bocio et al., 2004).

The mortality before the dry season (bds) on the year of plantation does not generally show significant differences among treatments, which seems to indicate a high genetic homogeneity of seedlings. After the dry season (ads), a high mortality was observed with clear differences between the SMPC and RCAV plots (slight soil disturbance) and the other treatments. Also in 2003 and 2004, mortality was observed only during the dry season, which emphasizes the effect of water deficit in the summer months, in soils under Mediterranean conditions. Similar results were obtained by Bocio et al. (2004), in similar climatic conditions, with species *Quercus rotundifolia*. In 2005, despite the severe/extreme drought, recorded at National level, there was no mortality, which may suggest that three years after installation, the plants were adapted to edaphoclimatic conditions of the experimental area. Gomes (1982) notes that mortality rate may be an indicator of species adaptation to the environmental conditions.

Taking into account the climatic characteristics of the study area (high summer water deficit), soil effective thickness proved to be a property determinant of survival, with good correlation between both variables in the years 2002, 2003 and 2004 (Table 4). Moreover, in plots in which soil effective thickness did not exceed 60 cm, the mortality was above 95% for both species. Querejeta et al. (2001) reported that under severe weather conditions, the rooting depth is crucial for survival and growth of forest species in stands newly installed. As expected, and confirmed by the results of other authors, water deficit has a remarkable effect on young plantations which have their root system at the surface layers and thus, are more sus-

Table 2
Mean soil chemical properties in 0–20 cm layer, one year after site preparation, according to the treatments. In the same line, different letters indicate significant differences between treatment means ($P < 0.05$).

Parameter	Treatments						
	TSMO	SMPC	RCAV	SRVC	RLVC	RCVC	RCLC
Organic C ($g\,kg^{-1}$)	11.4^{b}	11.1^{b}	8.3^{ab}	4.7^{a}	5.9^{a}	7.4^{a}	6.0^{a}
Total N ($g\,kg^{-1}$)	0.70^{b}	0.82^{b}	0.65^{ab}	0.46^{a}	0.57^{a}	0.59^{a}	0.47^{a}
P Olsen ($mg\,kg^{-1}$)	28^{ab}	47^{b}	40^{ab}	24^{a}	16^{ab}	32^{ab}	35^{ab}
Sum exchange bases ($cmol_c\,kg^{-1}$)	1.5^{a}	1.4^{a}	1.8^{a}	3.3^{b}	1.6^{a}	1.2^{a}	2.3^{ab}
pH (H_2O)	5.1^{a}	4.9^{a}	5.1^{a}	5.0^{a}	4.9^{a}	4.8^{a}	5.0^{a}

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Table 3
Actual cumulative mortality over the 3 years after plantation, for *PM* and *CS* species, according to the treatments. In the same column, different letters indicate significant differences between treatment means ($P < 0.05$).

Treatment	*Pseudotsuga menziesii* (*PM*)			*Castanea sativa* (*CS*)		
	2002	2003	2004	2002	2003	2004
	Mean ± standard error			Mean ± standard error		
SMPC	97.3 ± 2.7[a]	98.7 ± 1.3[a]	98.7 ± 1.3[a]	98.7 ± 1.3[a]	98.7 ± 1.3[a]	98.7 ± 1.3[a]
RCAV	87.0 ± 13.0[a]	87.0 ± 13.0[a]	87.0 ± 13.0[a]	88.7 ± 5.7[a]	90.4 ± 5.3[a]	90.4 ± 5.3[a]
SRVC	32.2 ± 6.1[b]	36.6 ± 7.8[b]	42.4 ± 9.8[b]	19.5 ± 10.2[b]	29.5 ± 20.2[b]	32.7 ± 18.9[b]
RLVC	34.2 ± 4.8[b]	43.2 ± 2.3[b]	43.2 ± 2.3[b]	19.6 ± 3.9[b]	19.6 ± 3.9[b]	19.6 ± 3.9[b]
RCVC	51.2 ± 8.4[b]	56.9 ± 8.3[b]	58.2 ± 8.0[b]	16.5 ± 9.2[b]	19.7 ± 3.6[b]	24.4 ± 6.2[b]
RCLC	48.0 ± 7.3[b]	48.0 ± 7.3[b]	48.0 ± 7.3[b]	44.8 ± 9.2[b]	47.4 ± 8.9[b]	48.8 ± 9.0[b]

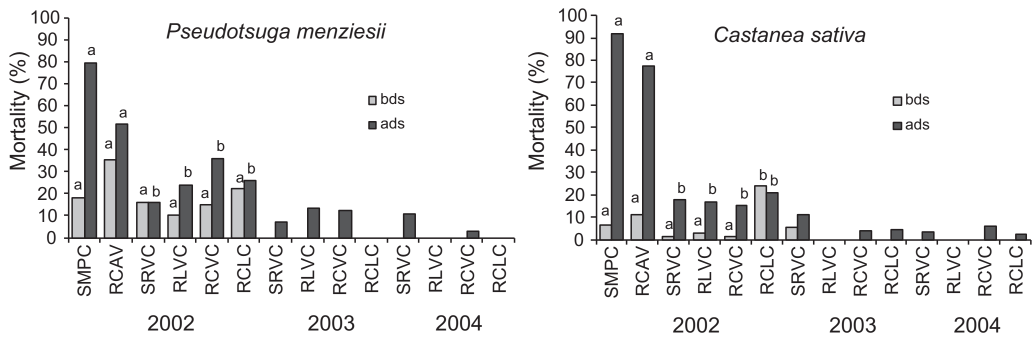

Fig. 6. Total mortality, before the dry season (bds) and after the dry season (ads), during the 3 years, for *PM* and *CS* species, according to the treatments. In the same year and for the same period (bds or ads), different letters indicate significant differences between treatment means ($P < 0.05$).

ceptible to the Mediterranean type of climate (Alves, 1988; Fernandes and Fernandes, 1998; Kanegae et al., 2000; Bocio et al., 2004).

For a better understanding of the plant behavior, the root system was observed. On SMPC plots there was generally a compact layer beneath 25–30 cm depth, which made it difficult for root penetration, as confirmed by direct observation of root systems configuration. On RCAV plots a large amount of coarse fragments was observed in the soil profile at about 30 cm or deeper, due to the effect of the ripper, which broke the parent material during subsoiling when site preparation was performed, but did not promote a good mixture with fine material. This insufficient mixture of coarse and fine materials was unfavorable for root growth, because of the poor plant/soil interface that prevails under these circumstances.

3.3. Species growth

Results concerning plant growth as affected by site preparation technique are presented in Tables 5–7 and in Fig. 7. The number of plants actually measured during the four growing seasons decreased from the initial 72 per treatment at plantation and 30–53, depending on treatment and species, 42 months later. However, it should be stressed that statistical computations were done considering height and diameter of the same individual plants in each treatment and measurement date, meaning a number of plants falling within the range mentioned above and depicted in Table 7. Comparable sample sizes are found in literature reporting similar studies (30 plants in Martins and Pinto, 2004; 60 plants in Madeira et al., 1989).

The influence of the treatments on growth of *PM* and *CS* (height and diameter) is shown in Table 5. For plant height, there are significant differences between treatments after 24 months in *CS* and 39 months in *PM*. However, from 24 months on, *PM* species shows sensible plant growth increase in RCLC when compared with the remainder treatments. As regards the diameter increase, the effect of the treatments is clear for both species but more delayed for *PM*. Height growth occurred only in spring (24–27 and 36–39 months) whereas the diameter growth occurred in spring and summer (27–30 and 39–42 months) (Table 5). This growth pattern is consistent with the strategy of adaptation to summer water deficits (Danner and Knapp, 2001). The mean increase in both height and diameter for each one of the species shows a very similar trend, but the response of the two species is completely different (Fig. 7). In fact, *PM* species shows a much steadier increase in height and diameter with time when compared with that of *CS*.

The relationship between soil effective thickness and plant growth, in general, strengthens with time after plantation (Table 6). This highlights the importance of creating conditions for an increased exploitation of soil volume by roots in the early years of plant establishment, as reported by several authors (Varelides and Kritikos, 1995; Querejeta et al., 2001; Abu-Hamdeh, 2003). Table 7 shows that there is a close and significant relation between the height of plants at plantation and that at 12 months, in both species, and the same

Table 4
Coefficients and significance of the correlation between soil effective thickness and mortality ($n = 18$ in each case) in the years 2002, 2003 and 2004 for *PM* and *CS* species (*$0.05 > P > 0.01$; **$0.01 > P > 0.001$; ***$P < 0.001$).

Species	Years		
	2002	2003	2004
PM	0.843***	0.863***	0.868***
CS	0.662**	0.643**	0.661**

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Table 5
Plant height and diameter at plantation (plant) and after 12, 24, 27, 30, 36, 39 and 42 months, for *PM* and *CS* species, according to the treatments. For each column of the same species and variable, different letters indicate significant differences between treatment means ($P < 0.05$).

Species	Treat	Plantation	Time (months)						
			12	24	27	30	36	39	42
Height (mean ± standard error (cm))									
PM	SRVC	8.2 ± 0.6^{a}	25.0 ± 1.5^{a}	47.5 ± 2.9^{a}	77.3 ± 4.2^{a}	78.1 ± 4.2^{a}	80.1 ± 4.5^{a}	125.5 ± 6.2^{ab}	126.8 ± 6.3^{ab}
	RLVC	5.8 ± 0.5^{a}	21.3 ± 0.9^{a}	43.9 ± 2.2^{a}	72.1 ± 3.6^{a}	72.9 ± 3.6^{a}	74.5 ± 4.0^{a}	119.4 ± 5.4^{ab}	122.5 ± 5.6^{ab}
	RCVC	7.7 ± 0.5^{a}	23.4 ± 1.3^{a}	42.6 ± 2.7^{a}	68.2 ± 4.5^{a}	68.6 ± 4.4^{a}	68.6 ± 4.6^{a}	106.5 ± 6.3^{b}	114.1 ± 6.6^{b}
	RCLC	8.5 ± 0.7^{a}	24.3 ± 1.2^{a}	49.5 ± 3.1^{a}	86.0 ± 5.0^{a}	87.5 ± 5.1^{a}	88.6 ± 5.7^{a}	144.5 ± 7.8^{a}	146.1 ± 7.9^{a}
CS	SRVC	35.8 ± 1.9^{a}	48.1 ± 1.8^{a}	72.1 ± 2.7^{ab}	96.7 ± 4.4^{ab}	97.4 ± 4.4^{ab}	99.8 ± 4.3^{a}	118.6 ± 6.3^{ab}	121.0 ± 6.3^{ab}
	RLVC	36.0 ± 1.5^{a}	50.6 ± 1.8^{a}	74.7 ± 2.2^{a}	97.4 ± 3.2^{a}	97.8 ± 3.2^{a}	99.0 ± 3.4^{ab}	123.1 ± 4.5^{a}	125.2 ± 4.6^{a}
	RCVC	34.3 ± 2.0^{a}	46.0 ± 1.8^{a}	64.5 ± 2.3^{b}	85.3 ± 3.2^{b}	85.6 ± 3.2^{b}	86.4 ± 3.2^{a}	106.3 ± 4.1^{b}	106.9 ± 4.1^{b}
	RCLC	34.6 ± 2.1^{a}	48.0 ± 2.3^{a}	70.5 ± 3.8^{ab}	100.4 ± 5.2^{a}	100.8 ± 5.3^{a}	102.9 ± 5.9^{b}	139.3 ± 8.9^{a}	140.7 ± 8.9^{a}
Diameter (mean ± standard error (mm))									
PM	SRVC	2.1 ± 0.1^{a}	7.3 ± 0.4^{a}	14.0 ± 0.7^{a}	18.2 ± 0.9^{ab}	21.8 ± 1.1^{ab}	22.8 ± 1.2^{ab}	30.3 ± 1.6^{ab}	32.4 ± 1.7^{ab}
	RLVC	2.1 ± 0.1^{a}	6.5 ± 0.4^{a}	12.7 ± 0.6^{a}	16.1 ± 0.8^{b}	19.2 ± 0.9^{b}	20.1 ± 1.0^{b}	28.2 ± 1.4^{b}	30.8 ± 1.6^{b}
	RCVC	2.0 ± 0.1^{a}	6.6 ± 0.4^{a}	13.0 ± 0.8^{a}	15.9 ± 1.0^{b}	19.6 ± 1.2^{b}	20.0 ± 1.3^{b}	26.0 ± 1.6^{b}	29.8 ± 1.7^{b}
	RCLC	1.9 ± 0.1^{a}	7.4 ± 0.5^{a}	15.2 ± 0.9^{a}	20.6 ± 1.1^{a}	25.5 ± 1.4^{a}	26.5 ± 1.6^{a}	35.8 ± 1.9^{a}	37.8 ± 2.0^{a}
CS	SRVC	6.7 ± 0.2^{a}	11.6 ± 0.4^{a}	20.0 ± 0.8^{ab}	24.6 ± 1.2^{a}	27.9 ± 1.4^{ab}	29.1 ± 1.4^{a}	35.8 ± 1.9^{a}	36.2 ± 1.9^{a}
	RLVC	6.6 ± 0.2^{a}	11.6 ± 0.4^{a}	19.7 ± 0.7^{a}	23.9 ± 0.9^{a}	27.0 ± 1.1^{a}	27.7 ± 1.1^{a}	34.1 ± 1.4^{a}	35.3 ± 1.5^{a}
	RCVC	6.0 ± 0.2^{a}	10.7 ± 0.3^{a}	17.1 ± 0.7^{b}	20.5 ± 0.9^{b}	23.3 ± 1.0^{b}	24.1 ± 1.0^{b}	29.3 ± 1.3^{b}	30.4 ± 1.4^{b}
	RCLC	6.6 ± 0.3^{a}	11.7 ± 0.5^{a}	19.8 ± 1.0^{a}	25.1 ± 1.3^{a}	29.1 ± 1.6^{a}	30.7 ± 1.8^{a}	38.1 ± 2.3^{a}	40.0 ± 2.5^{a}

Table 6
Coefficients and significance of the correlation of soil effective thickness (SET) with plant height and diameter on a 42-month period ($n = 12$ in each case) for the *PM* and *CS* species (*$0.05 > P > 0.01$; **$0.01 > P > 0.001$; ***$P < 0.001$).

Species	Time after plantation			
	12 months	24 months	36 months	42 months
Correlation SET vs plant height				
PM	0.354	0.440	0.530	0.575*
CS	0.151	0.487	0.583*	0.594*
Correlation SET vs plant diameter				
PM	0.422	0.346	0.462	0.469
CS	0.753**	0.715**	0.634*	0.644*

was observed in *C. sativa* for plant diameter, which seemingly reflects a high homogeneity of seedling material. Similar results were observed by Richter (1971) and cited by Carneiro (1995). During the two following growing seasons (12–24 and 24–36 months) this tendency decreased, emphasizing the growing influence of the environmental conditions with the age of plants.

In spite of the relationship found between treatments and plant growth, for the observed period it is not possible to define a general quantitative trend of growth based on the soil tillage intensity. Previous results under identical climatic conditions showed no significant differences on height and diameter growth for *Robinia pseudoacacia* (Martins and Pinto, 2004) and for *Eucalyptus globulus* (Madeira et al., 1989), due

Table 7
Coefficients and significance of the correlation between plant height and plant diameter at plantation and the same growth parameters after 12, 24 and 36 months, *PM* and *CS* (*$0.05 > P > 0.01$; **$0.01 > P > 0.001$; ***$P < 0.001$).

Species	Treatment (n)	Time after plantation		
		12 months	24 months	36 months
Correlation of actual plant height with that at plantation				
PM	SRVC (40)	0.495**	0.366*	0.308
	RLVC (38)	0.507**	0.295	0.260
	RCVC (30)	0.458*	0.256	0.307
	RCLC (37)	0.520***	0.265	0.287
CS	SRVC (46)	0.857***	0.250	0.036
	RLVC (53)	0.662***	0.162	0.048
	RCVC (51)	0.798***	0.301*	0.090
	RCLC (39)	0.788***	0.461**	0.424*
Correlation of actual plant diameter with that at plantation				
PM	SRVC (40)	0.347	0.376	0.312
	RLVC (38)	0.273	0.246	0.323
	RCVC (30)	0.523**	0.433*	0.407*
	RCLC (37)	0.246	0.266	0.117
CS	SRVC (46)	0.582***	0.218	0.098
	RLVC (53)	0.461***	0.378**	0.389**
	RCVC (51)	0.332***	0.052	0.030
	RCLC (39)	0.441***	0.285	0.226

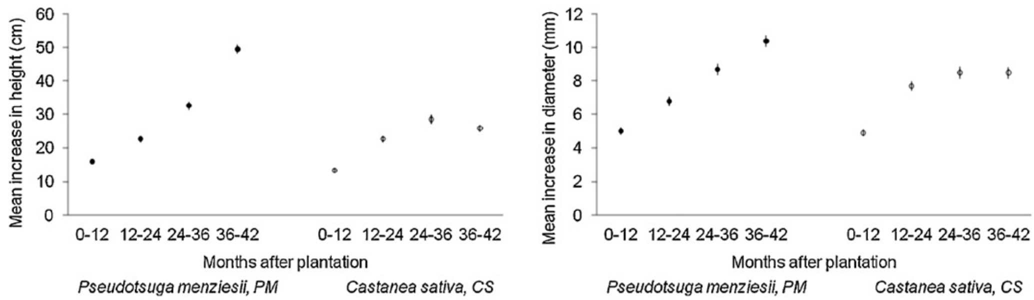

Fig. 7. Evolution of the plant height and diameter increments (mean ± standard error), in the first four growing seasons, for *PM* and *CS* species.

to different soil preparation operations, 30 months after plantation.

4. Conclusions

Mortality after planting was affected by the soil preparation technique, showing a very high mortality on the less intense treatments for both species, which can be ascribed to the higher summer water deficit on those treatments. No clear differences were observed on plant mortality for the other site preparation operations. A relation between growing and treatment was found, but it is difficult to quantitatively define a trend according to soil disturbance intensity; a longer period of time is certainly necessary to experimentally reach that goal. Soil conditions determined by soil preparation techniques significantly influenced mortality and growth of forest species under test in the experiment reported, and this has a special emphasis in the case of soil effective thickness. The relationship between the plant growth and soil depth increased with time.

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