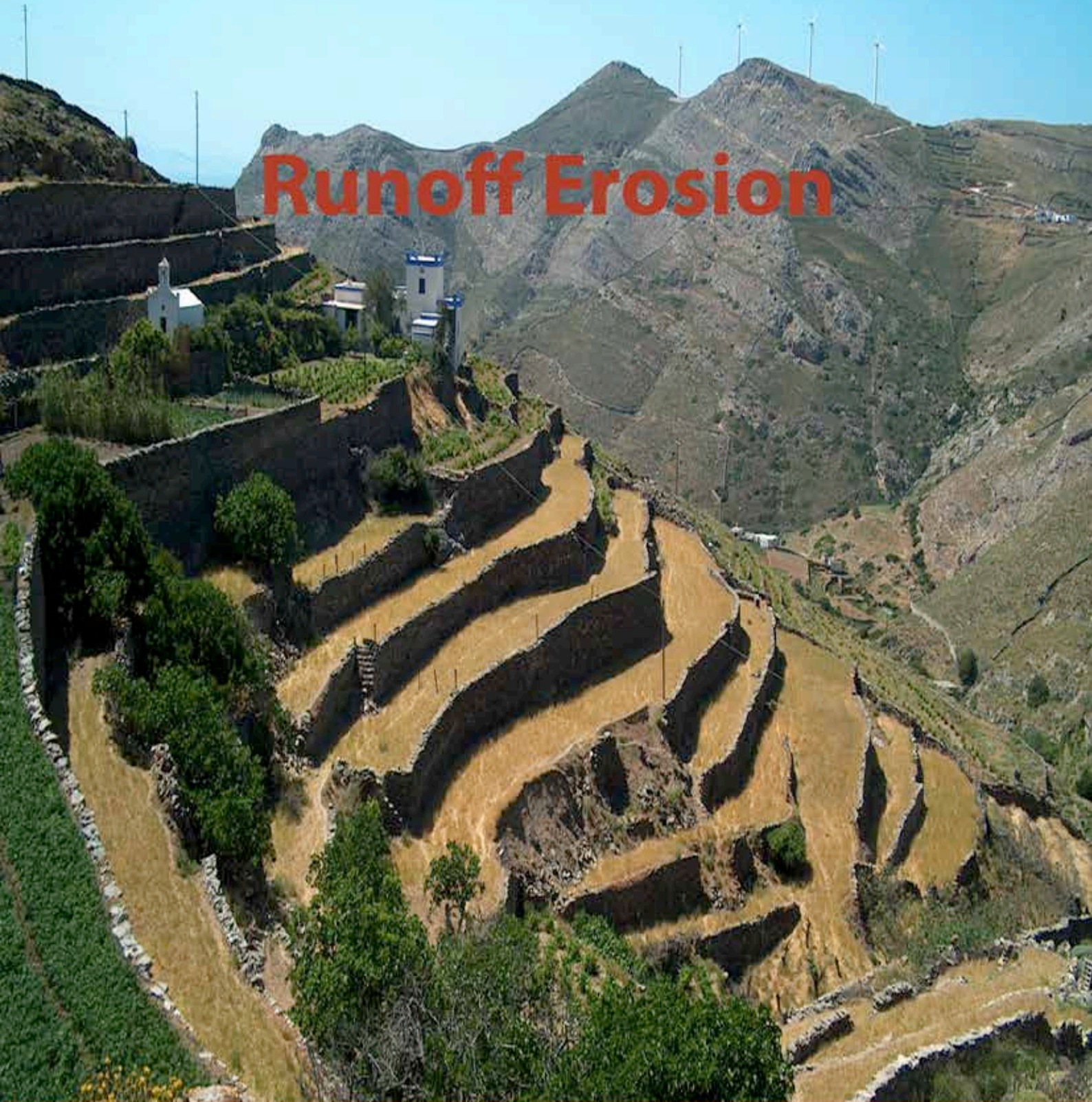


Runoff Erosion



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PART II - CASE STUDIES

CASE STUDY 3: SITE PREPARATION IMPACTS ON PHYSICAL AND CHEMICAL FOREST SOIL QUALITY INDICATORS

Felícia Fonseca, Tomás de Figueiredo and Afonso Martins

1. INTRODUCTION

Forest soils in the Mediterranean region frequently have limited rooting depth, high coarse elements and low organic matter content, which tend to limit water storage in the soil profile. Accordingly, application of site preparation techniques is essential to enhance soil water storage and availability in these environments (Querejeta et al., 2001; Alcázar et al., 2002; Piatek et al., 2003; Imaz et al., 2010). However, site preparation for afforestation currently lacks accurate planning, based on sound experimental results driving to techniques most adequate to each situation and respecting stand productivity and ecosystem sustainability requirements. Improving soil quality is one of the most important factors for sustaining the global biosphere and fundamental in forest systems sustainability (Wang and Gong, 1998). A simple set of established soil properties can provide useful information on soil quality (Sparling et al., 2004). Soil quality has been defined as “the capacity of a soil to function within ecosystem boundaries to sustain biological productivity, maintain environmental quality, and promote plant and animal health” (Doran and Parkin, 1994). Land use and management practices seriously impact the direction and degree of soil quality changes in time and space (Wang and Gong, 1998). Possibly the most significant impact of site preparation from a soil quality perspective is on rooting depth and soil hydrological processes, because increase the availability of resources that plants have access (water and nutrients). Runoff and sediment loss is commonly highest in the first few years after site preparation, for the reason that canopy cover is scarce and ground vegetation may be insufficient for controlling erosion (Lucci and Della Lena 1994; Figueiredo et al., 2011).

Taking in account the soil complexity and the high number of properties that can be monitoring, it is important to select the most appropriate to the objectives of soil management practices. For comparison different site preparation techniques (Schoenholtz et al., 2000) suggested as soil quality indicators, soil effective thickness, bulk density, soil penetration resistance, particle size, aggregate stability, organic

matter content, nutrient availability, cation exchange capacity (CEC), base saturation (BS) and pH, because these variables are generally sensitive to soil management practices. Due to inappropriate land use and management, soil erosion, acidification, nutrient depletion, pollution and other natural resource problems have been affected human development (Lal, 1990; Figueiredo et al., 2011).

The objectives for this study were (i) evaluate changes in physical and chemical properties as indicators of forest soil quality, owing to mechanical site preparation; (ii) to compare soil quality using well-known indicators for that forest systems such as rooting depth, bulk density, particle size and nutrients availability; (iii) based on soil quality and productivity to indicate which techniques are most appropriate for the region under study.

2. MATERIAL AND METHODS

This study is a part of a large project, where were tested several site preparation operations in the environmental impacts (soil erosion and carbon storage), behavior of forest species installed (mortality, height and diameter growth, biomass production) and evolution of soil properties. Details of the design of this experiment are available in another published works (Fonseca et al., 2011; Figueiredo et al., 2011). Accordingly, only a succinct review is presented here.

The experimental field was established near Macedo de Cavaleiros, Northeast Portugal at 41° 35'N and 6° 57'W, 660 to 701m altitude, mean annual temperature 12°C, mean annual rainfall 656 mm, with a typically Mediterranean seasonal distribution (INMG, 1991). According to FAO/UNESCO (1988), soils are dystric Cambisols and dystrict Leptosols developed on schist, in the area characterized as sandy-loam, with high stoniness, normally acid, moderate to poor in organic matter content, with low to very low P and low to moderate K contents (Agroconsultores e Coba 1991; Fonseca 2005).

Experimental design comprised three blocks, where six treatments representing different intensities of soil disturbance by mechanical operations for site preparation, were randomly distributed on experimental plots (Table 1). This table 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 chemical and physical soil properties. Site preparation techniques under test were selected among a set of commonly applied in afforestation schemes, yet with no consistent experimental base for such options.

Treatment	Description of site-preparation operations
TSMO	Original soil control (no intervention on the original abandoned field)
	Slight disturbance
SMPC	No subsoiling, no ploughing, plantation with hole digger (60 cm depth)
RCAV	Subsoiling over the whole area, with covering shovel (around 60 cm depth)
	Moderate disturbance
SRVC	No subsoiling, contour bunds shaped by two plough passes (around 90 cm depth)
RLVC	Subsoiling in future plantation rows, contour bunds shaped by two plough passes (around 90 cm depth)
	High disturbance
RCVC	Subsoiling over the whole area, contour bunds shaped by two plough passes (around 90 cm depth)
RCLC	Subsoiling over the whole area, contour ploughing over the whole area (around 90 cm depth),

Table 1 : Treatments related to six soil preparation operations before plantation

The species selected were *Pseudotsuga menziesii* (*PM*) and *Castanea sativa* (*CS*), which were planted at a distance of 4 x 2 m in alternate rows, with two rows for each plot, 12 plants in each row with a total of 24 plants per species. The plantation was made by hand, in February 2002, using nursery seedlings, *PM* in plastic bags and *CS* of bare root.

Before site preparation operations 48 soil profiles were observed, and one year after planting 6 soil profiles per treatment were observed in the plantation line. Soil samples were taken at 0-20, 20-40 and 40-60 to assess the effects of site preparation on soil properties and possible relationships with plant response. Soil quality monitoring was based on morphological properties observed in soil profiles and laboratory analysis of soil samples collected in the profiles. The soil properties chosen

in this study were selected taking in account the main factors limiting plant development in the Mediterranean region like water and nutrients. Thus, was considered to be relevant soil effective thickness, bulk density, clay content and soil organic C, because they have an important role in water storage, nutrient availability and root expansion. Chemical properties as total N, available P and K, exchangeable bases, cation exchange capacity and pH are relevant for biological activity and plant nutrition. Soil quality measures such as the ones proposed here can be usefully combined with measurements of soil loss (Sparling et al., 2004). Data on soil loss can be found in Figueiredo et al. (2011). In this work will be addressing the effects of soil erosion on soil properties, using an enrichment ratio (E), where $E = \text{nutrient content or other property in eroded sediment} / \text{nutrient content or other property in original soil}$ (Gachene et al., 1997). Thus, whenever $E > 1$ means that the eroded sediment was enriched in the element analyzed, in relation to original soil, which may indicate the occurrence of natural soil fertility loss by erosion action. Also, in order to identify differences in soil properties between original soil (TSMO) and site preparation operations (SMPC, RCAV, SRVC, RLVC, RCVC and RCLC), was applied the same idea of enrichment ratio (E), but now $E = \text{soil property in each site preparation operations} / \text{soil property in original soil}$. When $E > 1$ means that the soil property analyzed was improved with site preparation.

Soil samples collected in soil profiles, were air dried, sieved (mesh size 2 mm) and analysed for organic C (Walkley-Black method), total N (Kjeldahl method), available P and K ((Egner-Riehm method). Exchangeable bases were determined by atomic adsorption (Ca^{2+} and Mg^{2+}) and by flame emission spectrophotometry (K^+ and Na^+). Cation exchange capacity was calculated as the sum of exchangeable bases and exchangeable acidity. Soil pH was measured in a soil-water suspension (1:2.5 soil-water ratio). Effective soil thickness, defined as the set of layers most explored by plant roots, was measured in each profile during soil profile description. Bulk density was determined in undisturbed samples, weighting oven-dried soil (at 105 °C), collected in 100 cm³ cylinders in depths 0-5, 5-15, 15-30 and 30-60 cm. Particle size analysis was done by pipette method.

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. Simple correlation analyses were applied to estimate relationships between soil properties and variables measured in plants.

3. RESULTS AND DISCUSSION

3.1. Physical soil quality indicators

In slight soil disturbance treatments (SMPC and RCAV), the soil effective thickness (rooting depth) remains very similar to the original soil (TSMO), but in treatments with moderate and intensive site preparation (SRVC, RLVC and RCLC) there are a significant increase ranging from 30 to 40 cm (Fig. 1). The soil effective thickness is a property that varies very little over time and reflects the soil physical conditions ability for plant growth (Wang and Gong, 1998, Schoenholtz et al., 2000).

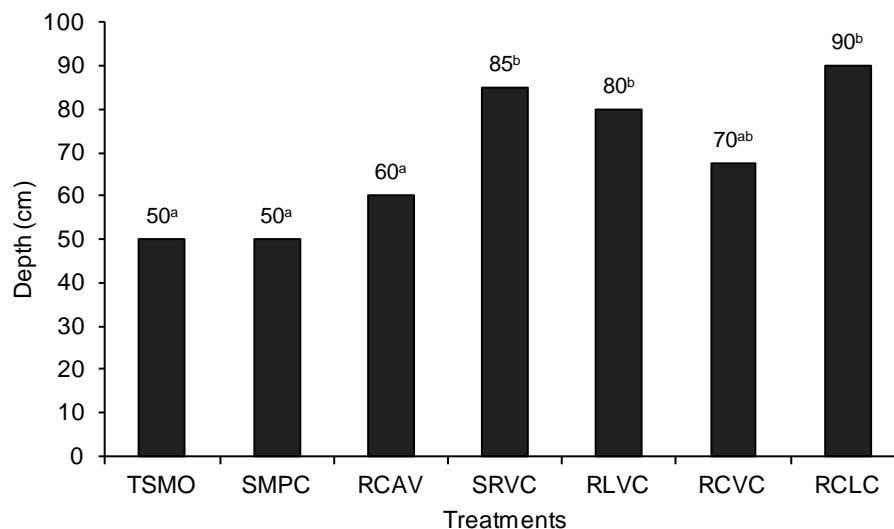


Fig. 1: Means of soil effective thickness one year after site preparation. For treatments, averages with the same letter are not significantly different ($P < 0.05$).

Given the climatic characteristics of the study area (high summer water deficit), the soil effective thickness proved to be a property determinant of survival and growth of forest species installed (Fig. 2), showing a good correlation at the end of 42 months with survival ($r^2 = 0.942$ and 0.745 , respectively for *PM* and *CS* species) and with the height and diameter growth for *PM* ($r^2 = 0.859$ and 0.781 , respectively) and *CS* ($r^2 = 0.919$ and 0.975 , respectively). Moreover, in plots in which soil effective thickness did not exceed 60 cm, the mortality was above 95% for both species (Fonseca et al., 2011).

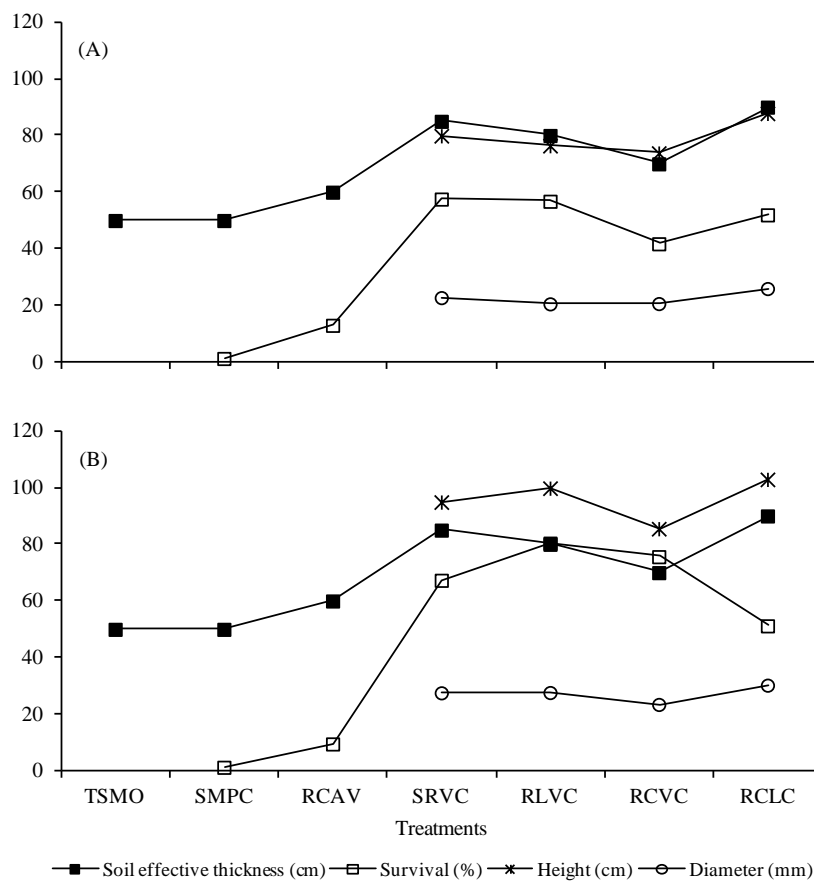


Fig. 2: Relationship of survival and growth in height and diameter of *PM* (A) and *CS* (B) species with the soil effective thickness, according to the treatments.

Also, treatments with moderate and intensive site preparation contributed to decrease bulk density in all depths considered. Bulk density values ranging from 1.44 to 1.76 g cm⁻³ in the original soil (TSMO) and 1.33 to 1.39 g cm⁻³ in RCVC treatment, respectively for 0-5 and 30-60 cm depth. The remaining treatments showed values intermediate to these (Fig. 3). Furthermore, intensification of site preparation also contributed to the reduction of spatial and vertical bulk density variability (see meaning letters of bars in Fig. 3), which favors water and oxygen availability (Schoenholtz et al., 2000) and root development (Logsdon and Karlen, 2004).

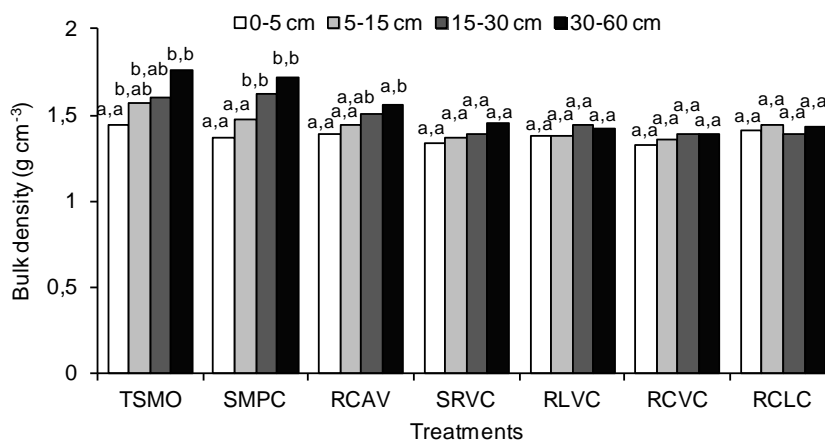


Fig. 3: Soil bulk density (g cm⁻³) per treatment and soil depth. The first letter indicates that for the same treatment, means followed by the same letter depths are not significantly different; the second letter indicates that for the same depth, means followed by the same letter treatments are not significantly different ($P < 0.05$).

Soil texture classes ranging among loam and sandy-loam (Table 2). However, there are variations in sand, silt and clay fractions, which can lead to differences in pore size and consequently cause differences in aeration conditions and soil water retention (Dexter, 2004). In general, there are no significant differences between treatments for the fine earth fraction (sand, silt and clay), but the treatments with furrow hillock surface soil (SRVC, RLVC and RCVC) show an increase in clay content in surface mineral layer (0-20 cm), showing a reverse trend in the deeper soil layers (20-40 and

40-60 cm), when compared with the original soil (TSMO). Once the young plants are essentially dependent on the moisture content of the surface layers (Fernandes and Fernandes 1998; Kanegae et al., 2000), these higher levels of clay can help increase water retention and nutrients absorption during summer rainfall, with positive impact on plantations' success.

Soil properties	Depth (cm)	Treatments						
		TSMO	SMPC	RCAV	SRVC	RLVC	RCVC	RCLC
Coarse sand (%)	0-20	37.9 ^a	35.2 ^a	32.6 ^a	33.1 ^a	27.7 ^a	35.0 ^a	37.6 ^a
	20-40	36.7 ^a	34.9 ^a	34.2 ^a	33.1 ^a	33.0 ^a	36.6 ^a	33.1 ^a
	40-60	42.1 ^b	36.4 ^b	33.6 ^{ab}	22.8 ^a	30.6 ^{ab}	39.8 ^b	35.6 ^b
Fine sand (%)	0-20	33.0 ^a	32.7 ^a	33.8 ^a	28.8 ^a	34.1 ^a	26.3 ^a	27.8 ^a
	20-40	29.4 ^a	26.2 ^a	32.7 ^a	32.0 ^a	32.4 ^a	32.3 ^a	32.7 ^a
	40-60	25.5 ^a	30.7 ^a	22.2 ^a	38.9 ^a	33.7 ^a	31.9 ^a	29.7 ^a
Silt (%)	0-20	18.6 ^a	21.1 ^{ab}	20.8 ^{ab}	24.2 ^{ab}	25.2 ^{ab}	27.5 ^b	25.9 ^{ab}
	20-40	19.0 ^a	19.9 ^a	19.6 ^a	24.6 ^a	23.5 ^a	20.8 ^a	21.4 ^a
	40-60	16.7 ^a	14.7 ^a	20.8 ^a	26.1 ^a	19.3 ^a	16.7 ^a	23.3 ^a
Clay (%)	0-20	10.6 ^{ab}	11.0 ^{ab}	12.7 ^{ab}	14.0 ^b	12.9 ^{ab}	11.1 ^{ab}	8.7 ^a
	20-40	14.9 ^a	19.1 ^a	13.5 ^a	10.3 ^a	11.2 ^a	10.3 ^a	12.5 ^a
	40-60	15.7 ^{ab}	18.3 ^{ab}	23.5 ^b	12.1 ^a	16.4 ^{ab}	11.6 ^a	11.4 ^a

Table .2 : Soil particle size distribution under different site preparation techniques (treatments). In the same line, means followed by the same letter are not significantly different ($P > 0.05$)

3.2. Chemical soil quality indicators

When compared with the original soil (TSMO), the treatments with moderate and high soil disturbance (SRVC, RLVC, RCVC and RCLC), contributed to a significant decrease in organic C concentration (59, 48, 35 and 47% for the SRVC, RLVC, RCVC and RCLC treatments, respectively) and total N (45, 33, 30 and 44% for the

same treatments, respectively) in surface layer (0-20 cm) (Table 3 and Fig. 4), being the result of the disruption of the balance between formation and mineralization humus processes (Madeira et al., 1989; Islam and Weil, 2000; Saviozzi et al., 2001). In the same treatments, C and N tends to increase in depth, showing significantly higher levels in deeper layer (40-60 cm), which is associated with the migration of organic matter in the soil profile by the action of tillage. Despite the changes observed in the levels of carbon and nitrogen, Dick et al. (1998) reported that the largest variations in organic matter content occur during the first five years after site preparation, with little variation beyond that period.

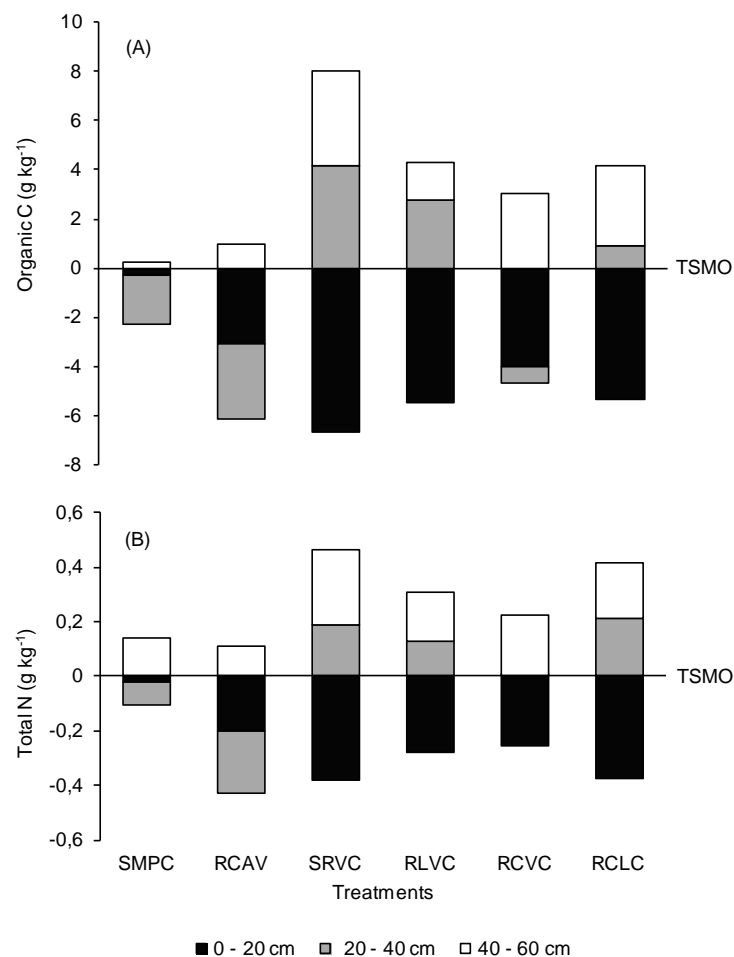


Fig. 4: Variation of soil organic carbon (A) and total nitrogen (B) in relation to the original soil (TSMO).

Soil properties	Depth (cm)	Treatments						
		TSMO	SMPC	RCAV	SRVC	RLVC	RCVC	RCLC
Organic C (g kg ⁻¹)	0-20	11.4 ^b	11.1 ^b	8.3 ^{ab}	4.7 ^a	5.9 ^a	7.4 ^a	6.0 ^a
	20-40	6.3 ^{ab}	4.3 ^{ab}	3.2 ^a	10.5 ^b	9.0 ^b	5.6 ^{ab}	7.2 ^{ab}
	40-60	2.5 ^a	2.7 ^a	3.5 ^a	6.4 ^a	4.0 ^a	5.5 ^a	5.7 ^a
Total N (g kg ⁻¹)	0-20	0.85 ^b	0.82 ^b	0.65 ^{ab}	0.46 ^a	0.57 ^a	0.59 ^a	0.47 ^a
	20-40	0.54 ^{ab}	0.46 ^{ab}	0.30 ^a	0.73 ^b	0.66 ^{ab}	0.54 ^{ab}	0.75 ^b
	40-60	0.29 ^a	0.43 ^{ab}	0.40 ^{ab}	0.57 ^b	0.47 ^{ab}	0.51 ^{ab}	0.49 ^{ab}
SEB (cmol kg ⁻¹)	0-20	1.52 ^a	1.39 ^a	1.77 ^a	3.32 ^b	1.57 ^a	1.19 ^a	2.26 ^{ab}
	20-40	1.71 ^a	1.67 ^a	2.02 ^{ab}	3.35 ^b	1.78 ^a	1.32 ^a	2.59 ^{ab}
	40-60	1.81 ^a	2.82 ^{ab}	3.04 ^b	1.53 ^a	1.97 ^a	1.67 ^a	1.22 ^a
CEC (cmol kg ⁻¹)	0-20	3.31 ^a	3.26 ^a	3.92 ^a	6.57 ^b	3.63 ^a	3.30 ^a	4.59 ^a
	20-40	4.24 ^a	4.43 ^a	4.16 ^a	5.35 ^a	4.68 ^a	3.29 ^a	4.31 ^a
	40-60	5.26 ^a	5.32 ^a	6.42 ^a	4.66 ^a	4.30 ^a	5.34 ^a	4.24 ^a
BS (% CEC)	0-20	47.1 ^a	42.5 ^a	43.0 ^a	44.8 ^a	43.2 ^a	36.7 ^a	50.2 ^a
	20-40	42.8 ^a	41.5 ^a	48.9 ^a	48.8 ^a	38.6 ^a	39.3 ^a	45.2 ^a
	40-60	39.8 ^a	50.6 ^a	51.4 ^a	34.5 ^a	46.3 ^a	36.8 ^a	32.0 ^a
pH (H ₂ O)	0-20	5.1 ^a	4.9 ^a	5.1 ^a	5.0 ^a	4.9 ^a	4.8 ^a	5.0 ^a
	20-40	5.0 ^a	4.9 ^a	5.0 ^a	4.9 ^a	4.9 ^a	4.9 ^a	5.0 ^a
	40-60	5.0 ^a	4.9 ^a	5.0 ^a	4.8 ^a	5.0 ^a	5.0 ^a	4.7 ^a

SEB - sum exchange bases; CEC - cation exchange capacity; BS - base saturation

Table 3: Chemical soil properties under different site preparation techniques (treatments). In the same line, means followed by the same letter are not significantly different ($P > 0.05$)

Available P values (Fig. 5A) range from very low (0-25 mg kg⁻¹) to low (26-50 mg kg⁻¹) (Santos, 1991). These values can be related to phenomena of retention and fixation, tending to increase with depth and tillage intensity, which is very important because Portuguese soils are very poor in this nutrient (Arrobas and Coutinho, 2002).

However, these concentrations do not necessarily mean that there are deficiencies of phosphorus given the presence of mycorrhizal fungi (commonly observed during root systems observation) to promote plant nutrition, including phosphorus absorption, even if it is in low concentrations in soil (Binkley, 1986; Honrubia, 1992). In relation to available K (Fig. 5B), this shows values considered moderate (51-100 mg kg⁻¹) (Santos, 1991). Site preparation techniques influenced positively the potassium availability owing to changes in other factors such as aeration, temperature and moisture content (Sharma et al., 2005), but without a consistent trend.

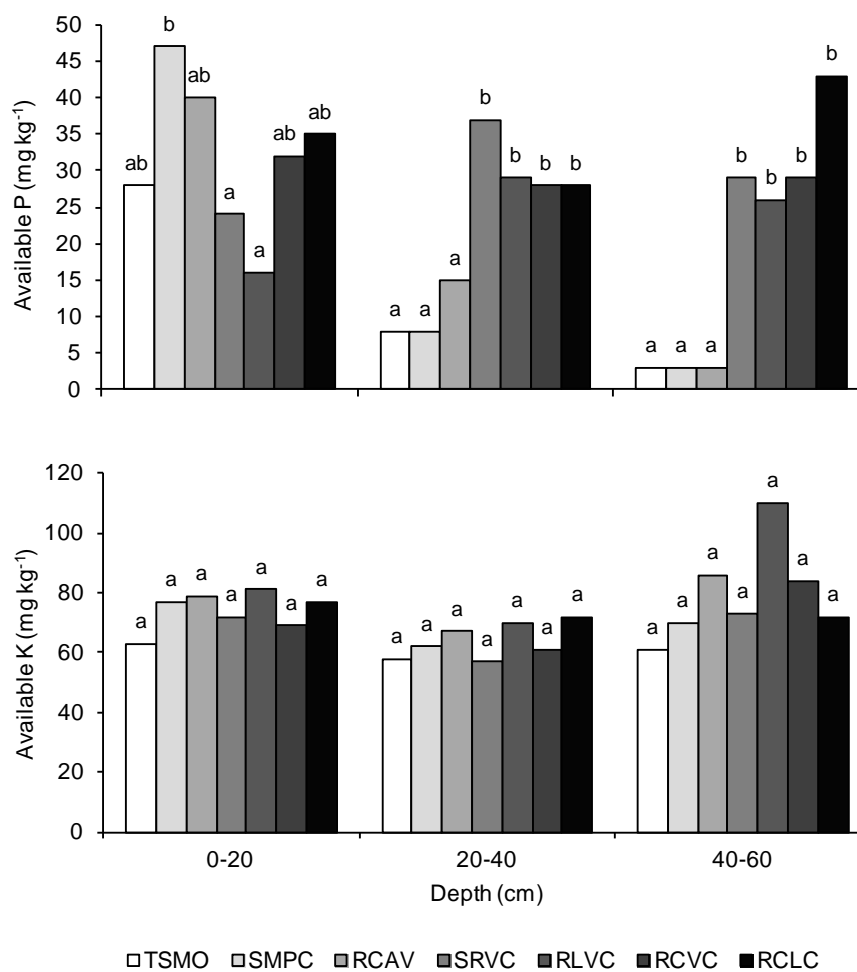


Fig. 5: Available phosphorus (A) and potassium (B) one year after site preparation. For treatments, averages with the same letter are not significantly different ($P < 0.05$).

In surface soil layer, sum of exchangeable bases increase, although only significantly in SRVC (Table 3). These values are considered very low (Metson,

1956), which is justified by the lithology of the parent material and leaching phenomena. Calcium is the most important basic cation in the soil, contributing around 70% for the sum exchangeable bases.

3.3. Enrichment of surface soil layer and eroded sediment after site preparation

Values of enrichment ratios (E) for clay, soil organic C, total N, available P and K, exchange bases (Ca^{2+} and Mg^{2+}), cation exchange capacity (CEC) and pH (H_2O) of the surface soil layer (0-20 cm) and eroded sediment are depicted in Table 4. Data for RCLC treatment are missing because the high surface ground roughness after site preparation was such that erosion monitoring was discarded.

Parameter	Treatments				
	SMPC	RCAV	SRVC	RLVC	RCVC
Surface soil layer (0-20 cm) (TSMO values equal 1)					
Clay (%)	1.13a	1.31a	1.44a	1.33a	1.25a
Organic C (g kg^{-1})	0.98a	0.73a	0.41a	0.52a	0.65a
Total N (g kg^{-1})	0.97a	0.76a	0.55a	0.67a	0.70a
Available P (mg kg^{-1})	1.68b	1.43b	0.86a	0.57a	1.14a
Available K (mg kg^{-1})	1.22a	1.25a	1.14a	1.29a	1.10a
Ca^{2+} (cmol kg^{-1})	0.95a	1.25a	2.21b	1.10a	0.84a
Mg^{2+} (cmol kg^{-1})	0.75a	1.13a	2.84b	0.94a	0.56a
CEC (cmol kg^{-1})	0.98a	1.18a	1.98b	1.10a	1.00a
pH (H_2O)	0.96a	1.00a	0.98a	0.96a	0.94a
Eroded sediment (Treatment surface soil values equal 1)					
Clay (%)	0.60a	0.62a	0.53a	0.67a	0.84a
Organic C (g kg^{-1})	1.50b	1.05a	1.40b	0.91a	1.46b
Total N (g kg^{-1})	2.02b	1.35a	2.29b	1.42a	1.14a
Available P (mg kg^{-1})	0.82a	0.48a	0.56a	0.64a	0.73a
Available K (mg kg^{-1})	1.57b	0.96a	1.24a	1.68b	1.57b

Ca ²⁺ (cmol kg ⁻¹)	1.43b	0.96a	1.11a	0.82a	1.05a
Mg ²⁺ (cmol kg ⁻¹)	2.20b	1.02a	1.55b	1.69b	1.11a
CEC (cmol kg ⁻¹)	0.95a	0.65a	0.75a	0.77a	0.73a
pH (H ₂ O)	1.06a	1.06a	1.05a	1.07a	1.04a

CEC - cation exchange capacity

Table 4: Enrichment ratios (E) of surface soil layer (0-20 cm) and eroded sediment according to the treatments t. In the same line, means followed by the same letter are not significantly different (P > 0.05)

When compared with original soil, site preparation increased clay content and nutrients availability in soil (usually $E > 1$) with the exception of organic C and total N, as a result, site preparation can have several positive effects on soil quality in Mediterranean region. In eroded sediment E were higher than unity for almost all sediment elements, being particularly high for total N, available K and Mg²⁺. Clay content showed $E < 1$, which was unexpected because majority of soils preferentially lose clay particles in eroded sediment. Gachene et al. (1997) obtained similar results. Soil pH E is slightly above unity, which highlights the enrichment of the sediment in exchange bases in relation to original soil. Soil organic C and total N losses associated with site preparation techniques and soil erosion could be the major environmental problem in this region and could have adverse effects on physical and chemical soil properties. However, the low sediment production, about 1 t ha⁻¹ yr⁻¹, (Figueiredo et al., 2011) observed during this study showed that the damage to the system by erosion was hardly noticeable.

4. CONCLUSIONS

The site preparation techniques applied to install a mixed forest stand in a Mediterranean region, as reported in this paper, contributed to the increase of soil effective thickness and decreased of soil bulk density. In slight soil disturbance treatments (SMPC and RCAV), the tillage effects are not so evident, approaching the characteristics of these soils to the original situation (TSMO), resulting in high mortality of forest species planted, so they are not recommended for the region under study. In treatments with moderate disturbance (SRVC and RLVC), despite the

significant reduction of the carbon and nitrogen, contributed to an overall improvement of soil quality indicators (clay, soil effective thickness, bulk density, available P and K, etc), as well as, to the highest rates of survival and a good height and diameter growth 42 months after stand installation. Treatments with the highest intensity of site preparation operations (RCVC, RCLC), associated with rising production costs and possible worsening of environmental impacts, did not compensate these drawbacks with improvements in soil properties and plantations' success. Sediment loss due to site preparation was low (about 1 t ha⁻¹ yr⁻¹), consequently the soil fertility loss associated with soil erosion was of little relevance. Thus, in the region under study, the treatments SRVC and RLVC proved to be more sustainable for forest stands installation. Finally, it is important to note that the type of site preparation technique is extremely important in soils from areas where annual rainfall distribution shows a misfit with the growing season, as occurs in the Mediterranean region.

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