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Effects of site preparation and postplanting cultural treatments on the establishment and early growth of maritime pine (*Pinus pinaster* Ait.)

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Abstract: Maritime pine (*Pinus pinaster* Ait.) is a fast-growing pine species of the western Mediterranean Basin with important ecological (e.g., site restoration), economic (e.g., wood production), and social (e.g., recreation) values. Due to global climate change, the growing incidence of drought and wildfires challenges the distribution and growth of maritime pine. Mechanical site preparation (SP) either alone or integrated with chemical weed control can enhance site conditions for conifer seedlings, specifically by improving the physical and chemical condition of the soil and eliminating weeds. The study was established in the eastern Marmara Region of Turkey and included various SP techniques and cultural treatments (CT) of differing intensity applied in a factorial design before the plantation of one-year-old maritime pine seedlings. The SP treatments included raking by a bulldozer (SPB), raking by a bulldozer and then spraying with 1%-(v:v) glyphosate (SPH), and raking by a bulldozer followed by the broadcasting of the subsoil via bulldozer (SPS), the latter being the standard and the most intensive forest management SP treatment. The CT included various combinations of hoeing and foliar applications of glyphosate after planting. The SPH treatment was the overall best SP treatment in terms of seedling performance and physical and chemical soil properties at one and two YAT. The most intensive treatment (SPS) resulted in significantly reduced seedling growth, survival, and deterioration of physical and chemical soil properties, especially soil organic matter and nutrients. Hoeing in a 1-m radius around seedlings one year after planting (i.e. once during the experiment) (H1) significantly improved seedling survival and vigor compared to the control (H0). No additional gain in seedling survival or growth occurred with more intensive CT combinations. In summary, hoeing at the end of the first summer (H1) following the SPH is recommended for enhanced early seedling performance and soil productivity.

Key words: Glyphosate, hoeing, industrial plantation, mechanical site preparation

1. Introduction

Maritime pine (*Pinus pinaster* Ait.) is a fast-growing pine species of the arid and semiarid western Mediterranean Basin, southeastern Europe, and northwest Africa, with a range exceeding 4 million ha (Alia et al., 2009; Sánchez-Gómez et al., 2017; Karamanoli et al., 2017; Kandemir and Mataracı, 2018). This pine has significant ecological, economic, and social values including biodiversity, prevention of soil erosion, restoration of degraded sites, industrial wood production, and recreation (Le Maitre, 1998; Sanchez- Gomez et al., 2017; Guignabert et al., 2018).

Many fast-growing tree species (40 species) including exotic species have been tested in provenance trials in the Aegean, Black Sea, Marmara, and Mediterranean Regions for adaptability and rapid growth performance (Karakaş, 2003). The trials indicated that maritime pine is the species that can most extensively be used in industrial plantations in Turkey. The Corsican origin of maritime pine particularly was selected due to its desirable characteristics including rapid growth, straight bole, and resistance to snow (Tunçtaner et al.1985, 1988). Maritime pine is now considered a naturalized conifer in Turkey with a total area of nearly 60,000 ha (Güner et al., 2019). It particularly grows well on afforestation sites in the coastal regions of the Aegean, the Black Sea, and Marmara Regions of the country (Ürgenç and Boydak, 1981; Tunçtaner and Tulukçu, 1990; Birler, 2009; Tunçtaner et. al., 2012; Özel et al., 2021).

Due to global climate change, the occurrence and impact of unusual weather incidents including floods, wildfires, and drought have increased dramatically in the last half-century (IPBES, 2019). In particular, the Mediterranean Basin (including Turkey) is projected to suffer from the effects of global climate change, and an increase in arid and semiarid areas is expected (Feng and Fu, 2013; FAO, 2019; Türkeş et al., 2020; Bağçaci et. al.,

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2021). Although maritime pine is a drought-tolerant forest tree species, the mounting incidences of drought and wildfires threaten the distribution and growth of this pine species (Fernandes and Rigolot, 2007).

Studies that model the range and growth of maritime pine against various environmental variables have indicated that soil's physical and chemical properties are key to the distribution and growth of this conifer (Barrio-Anta et al., 2020; Özel et al., 2021). Weeds usurp site resources such as water and nutrients from the soil and solar radiation. Therefore, they pose a major threat to the establishment and growth of newly planted forest tree species (Wagner et al., 2004; Eşen et al., 2005). Proper selection and application of herbicides can significantly eliminate unwanted vegetation in afforestation sites (Radosevich et al., 2007).

Site preparation (SP) is a common forestry practice to enhance site conditions, specifically, the physical and chemical conditions of the soil including moisture and nutrient availability, aeration, and drainage. These methods also substantially reduce weed competition, thereby channeling limited site resources to the crop species (Cardoso et al., 2020; Steele et al., 2021). The use of mechanical site preparation along with herbicides particularly enhances the establishment and growth of fast-growing conifer species in plantations (Mohler et al., 2021) including those of slash pine (*Pinus elliottii* Engelm) and loblolly pine (*P. taeda* L.) in the southeastern USA (Zao et al., 2009) and maritime pine in Europe (Varelides and Kritikos, 1995; Thivolle-Cazat and Najar, 2001). With these benefits, proper use of site preparation may help mitigate global climate change effects in environments projected to be increasingly limited in resources, in particular water and nutrients (Cortini et al., 2010; Cardoso et al., 2020).

Afforestation is the most common forestry practice in Turkey for restoring degraded sites (Yıldız et al., 2022). Mechanical SP has been commonly employed for the establishment of maritime pine plantations (Cooling, 1977; Tolay et al., 1984; Hızal et al., 2002, 2007; Tunçtaner et al., 2012). However, considering the tree species, weeds, climate, and management objectives in the selection of the proper type and intensity of silvicultural SP methods play a pivotal role in achieving success in the establishment of plantations of tree species (Cardoso et al., 2021), including maritime pine (Tunçtaner et. al., 2012). Failures in the establishment and development of maritime pine plantations in Turkey originate largely from improper selection of seed sources and SP methods (Tunçtaner et al., 2012). In intensive forest plantation sites in Turkey, the standard method involves raking, followed by subsoiling using bulldozers equipped with rippers (Hızal et al., 2007). However, concerns have arisen about the negative impact of highly intensive mechanical SP treatments on soil productivity and tree growth (Yıldız et al., 2007, 2009), specifically for maritime pine plantations (Hızal et al., 2007). Moreover, information is very limited on the effects of SP methods integrated with chemical weed control on the establishment and early growth of maritime pine plantations in Turkey.

In Turkey, industrial pine plantations are generally established in the Marmara and the Black Sea Regions. The northern part of the Marmara Region is completely under the influence of the Black Sea climate, and weeds are the main problem in afforestation studies. In recent years, to overcome this problem, the topsoil is scraped with the dozer blade and the living cover is cleaned. During this process, the fertile topsoil is stripped and piled up as wastes, and it is thought that yield losses are experienced. With this study, land preparation practices that will make it possible to keep the fertile topsoil in place have been the subject of the research.

This study investigated the effects of various combinations of site preparation (SP) treatments and cultural practices (CT) including herbicide applications on the establishment and early growth of a one-year-old maritime pine plantation. The study also examined various physical and chemical soil properties in the eastern Marmara Region of Turkey. This study aims to identify the most successful main treatments (SP and CT) and especially the treatment combination (SP × CT) for enhanced early seedling performance (survival and growth) and soil productivity. Enhanced seedling performance by the best management practice will increase significantly the total productivity of the stands of maritime pine. Identifying the most appropriate treatment combination will also improve the species' adaptive capacity to the effects of global climate change, particularly drought.

2. Material and methods

2.1. Site description

The experiment was carried out in the Mollafenari Sub-District of the İzmit District Forest Management Division of the İzmit Regional Forest Management Directorate in the western Black Sea Region of Turkey (40º58'13"N; 29º33'31"E). The site formerly accommodated a 30-year-old maritime pine plantation that was clear-cut in 2014. The study site has a semiarid climate with a mean annual temperature and precipitation of 14.7 °C and 656 mm, respectively. The summer drought period starts in May and ends in October during the year with the most intense drought occurring in July-August. The mean minimum temperature is 2.3 °C (January) whereas the mean maximum temperature is 19.9 °C (August). The study site has an elevation of 290 m (a.s.l.) and a northern aspect. The soil texture is mainly loamy with moderate-to-slight acidic (pH: 5.6). The soil organic matter of the site is 6%. The vegetation of the site includes *Cistus* sp., *Quercus cerris,* *Quercus petrea*, *Cerasus avium*, *Carpinus betulus*, *Laurus nobilis*, *Rubus* sp., *Smilax* sp., *Arbutus unedo*, and *Erica* sp.

2.2. Treatments

Three different site preparation (SP) treatments and seven cultural treatments (CT) were employed for this experiment. The SP treatments were carried out in June 2015 and included the SPB (SP-basic), the SPH (SP-herbicide), and the SPS (SP-standard). For the SPB, using a bulldozer (Komatsu® D85-A18 250 HP) equipped with a rake blade, the tall, woody weeds and logging residue on the site were raked into windrows without removing the tree stumps left one year after clearcutting. For the SPH treatment, in addition to the SPB, in August 2015, the plots were sprayed with glyphosate [N-(Phosphonomethyl) glycine, Firewall® SC (360 g l^{-1})] foliar herbicide at a rate of 1% (v:v) using an agricultural tractor mounted with a 500-L tank. For the SPS treatment, which is the standard SP treatment used by forest management, in addition to the SPB, but with the tree stumps removed, the SPS treatment was applied by broadcasting the soil using the bulldozer equipped with a two-tooth ripper.

In December 2015, one-year-old maritime pine seedlings of Kerpe-İzmit origin procured from the Sındırgı-Balıkesir Forest Nursery were planted in the experimental site plots at 2 × 2 m spacing. The seedlings used in the study had been propagated from the seeds collected from the Corsica origin maritime pine seed stand in the Kerpe Research Forest of the Poplar and Fast Growing Forest Trees Research Institute in Kerpe, İzmit, Turkey.

The application of cultural treatments (CT) began in 2016. These consisted of the H0 (control), H1 (standard forest management CT) which included hoeing by hand a 1-m radius around the seedlings one year after planting (YAP) (i.e. once during the experiment), H2 which consisted of weeding and hoeing around seedlings one and two YAP (i.e. twice during the experiment), H3 that included the foliar application of glyphosate to a 1-m radius around the seedlings one YAP, H4 that used a foliar application of glyphosate around the seedlings one and two YAP (i.e. twice during the experiment), H5 that included both hoeing and foliar application of glyphosate around the seedlings one YAP, and H6 that combined both hoeing and foliar application of glyphosate around the seedlings one and two YAP (i.e. twice during the experiment). The foliar application of glyphosate was carried out at a 1% rate (v:v) using a conventional 5-L polyethylene plastic knapsack sprayer. Plastic buckets were used to shield the seedlings during the foliar herbicide application to prevent them from coming into direct contact with the chemical solution. The herbicide application and hoeing by hand were performed in May and September, respectively during the year.

2.3. Soil sampling and analysis

Various physical and chemical soil analyses were carried out using 12 samples taken at a 0–10 cm soil depth from the different site preparation plots two years after treatment (YAT). The soil samples were air-dried and sieved to the fraction size of <2 mm before chemical analysis (Fidan, 2017). Soil texture was determined using the Bouyoucos hydrometer method (Gee and Bauder, 1986). The organic carbon content was determined via the Walkley and Black wet digestion method (Walkley and Black, 1934). A glass electrode was used to determine soil acidity (1.0:2.5 soil/water), whereas electrical conductivity was determined in a 1.0:2.5 water/soil solution (Fidan, 2017). Soil P (P_2O_5) was extracted using the Olsen method, which is more suitable for calcareous soil (Karaöz, 1989; Fidan, 2017). Exchangeable soil cations (K, Ca, Na, and Mg) were analyzed by an atomic absorption spectrometer (AA-6601 F; Shimadzu Corporation, Kyoto, Japan) using ammonium-acetate-extracted soil samples (Helmke and Sparks, 1996; Suarez, 1996). For the total N analysis, oven-dried (60 °C) samples were digested according to the micro-Kjeldahl method (Gerhardt Vapodest 45s) using a Buchi KjelFlex, K-360 analyzer (Bremner, 1996). The soil analyses were carried out at the Soil Testing Laboratory of the Directorate of the Poplar and Fast Growing Trees Research Institute of the General Directorate of Forestry in İzmit, Turkey (Fidan, 2017).

2.4. Measurements

The mean seedling survival rate (%) was determined at the end of the growing seasons one and two YAT. The root-collar diameter (RCD, mm) and height of each pine seedling (cm) were measured to calculate the mean RCD and height one YAT (2017) and two YAT (2018) at the end of the growing season. The height-to-RCD (H/RCD) ratio was also calculated for each seedling in the same plot to determine seedling vigor (Opio et al., 2000) one and two YAT.

2.5. Experimental design and analysis

Experimental plots measured 50 × 50 m. A factorial (3 × 7) randomized complete block design with four replications was used for the experiment. Treatment effects for seedlings were analyzed using a two-way analysis of variance (ANOVA):

$$\mu_{i,j} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{i,j}$$, where

μ is the overall (grand) mean; α_i is the main effect of SP; β_j is the main effect of CT; $(\alpha\beta)_{i,j}$ is the interaction effect between SP and CT.

A one-way ANOVA was carried out using the soil analyses for physical and chemical properties to determine the SP main effect. Treatment means were separated using the Duncan Mean Separation Test at a $p \leq 0.05$ significance level. Data were tested for normality and were transformed when appropriate. The transformations used when appropriate were stated in tables. The SAS was employed for the statistical analysis (SAS Institute Inc., 1996).

3. Results

The SP × CT interaction effect was not significant for any of the dependent variables one and two YAT. However, a significant SP main effect was found for all of the dependent variables one and two YAT (Table 1). The mean RCDs of the SPS and SPH seedlings were significantly greater (57% and 64%) than that of the SPB seedlings one YAT, respectively. There was no significant difference between the former two treatments for mean seedling RCD one and two YAT. The SPH treatment seedlings averaged a significantly greater mean height (20% and 44%) when compared to the SPS and SPB seedlings, respectively, one YAT. The SPS seedlings had a significantly greater mean height (19%) than the SPB seedlings. The superiority of the SPH treatment over the other two treatments for height growth was less, yet still significant (>10%) two YAT. The mean H/RCDs of the SPB and SPH seedlings were significantly greater (>19%) than the mean RCD of the SPS seedlings one YAT, although the former two treatments did not vary considerably for the H/RCD. At the end of the second YAT, the SPB treatment averaged significantly greater H/RCD (>32%) than did the SPH and SPS treatments. The SPB and SPH seedlings demonstrated a significantly greater (nearly two-fold) mean survival rate compared to the mean survival rate of the SPS treatment both one and two YAT. There was no significant difference in seedling survival rate between the former two treatments one and two YAT (Table 1).

A significant CT main effect was also found for the H/RCD and survival rates one and two YAT (Table 2). The H2 and H6 treatments had the lowest seedling H/RCD among all the CTs, with significant differences one and two YAT. The H1 and H2 treatments averaged the greatest mean seedling survival rate, whereas the H0 seedlings had the lowest. However, many of the differences among the treatments were not significant one and two YAT.

At the end of the experiment, significant differences were found among the SP treatments for soil organic matter content (SOM), sand, silt, clay, EC, pH, and concentrations of P, K, and Mg (Tables 3 and 4). No significant differences were found among the SPs for N and Na. Although the mean SOM on the SPB and SPH plots did not significantly differ, they were significantly greater (> 2-fold) than the mean SOM on the SPS plots (Table 3). The soils of the SPS plots, however, averaged significantly greater (>14%) mean percent of sand than the SPB and SPH treatments. No significant difference was found between the latter two treatments for this variable. The SPH plots showed a significantly greater (18 and 95%) soil silt content compared to those of the SPB and the SPS, respectively. The mean percent of silt content in the soils of the SPB treatments was also significantly greater (65%) than that of the SPS treatment. Clay content in the soil significantly increased (31% and 43%) on the SPS plot sites compared to the clay content on the SPB and SPS plot

Table 1. Effects of site preparation treatments (SP) on the mean (± standard errors) root-collar diameter (RCD), height, vigor (H/RCD), and survival rate of maritime pine one year and two years after treatment (YAT) with standard errors.

SP[1]	RCD[2] (mm)	Height[2] (cm)	H/RCD[2]	Survival[2] (%)
	1 YAT			
SPB	6.15 ± 0.28 b	36.25[1] ± 1.44 c	60.3 ± 2.2 a	71.43 ± 3.83 a
SPH	9.80 ± 0.54 a	52.18 ± 1.54 a	55.6 ± 2.0 a	77.29 ± 3.76 a
SPS	9.68 ± 0.63 a[3,4]	43.21 ± 2.14 b[5]	46.4 ± 1.5 b[4]	41.14 ±2.79 b
	2 YAT			
SPB	11.35 ± 0.58 b	77.61 ± 2.22 c	71.7 ± 2.9 a	70.43 ± 4.16 a
SPH	20.84 ± 1.20 a	99.39 ± 2.29 a	50.7 ± 2.2 b	75.14 ± 3.89 a
SPS	18.56 ± 1.34 a[3,5]	90.04 ± 3.19 b	51.9 ± 2.1 b[5]	39.14 ± 2.76 b

[1] SPB: Raking weeds and logging residue into windrows with no stump removal by bulldozer; SPH: SPB + foliar spraying with glyphosate SPS: standard treatment or tree stump removal + broadcasting ripping by the bulldozer.
[2] Site preparation main effect was significant one and two YAT ($p \leq 0.05$).
[3] Means within the same column with different letters were significantly different ($p \leq 0.05$).
[4] Transformed (square root) values were employed for mean separation.
[5] Transformed (log) values were employed for mean separation. Nontransformed values were used for actual means.

Table 2. Effects of cultural treatments (CT) on the mean (± standard error) vigor index (H/RCD, in the same unit and survival rate of maritime pine one year and two years after treatment (YAT).

CT[1]	H/RCD[2]	Survival (%)[2]
1 YAT		
H0	59.42 ± 3.82 a[3,4]	54.67 ± 7.44 c
H1	54.42 ± 2.89 ab	69.00 ± 7.14 ab
H2	44.58 ± 2.22 c	71.67 ± 5.92 a
H3	61.00 ± 4.02 a	58.00 ± 7.33 bc
H4	54.08 ± 2.46 ab	61.00 ± 6.75 abc
H5	55.25 ± 3.94 ab	61.00 ± 7.86 abc
H6	50.17 ± 1.89 bc	67.67 ± 6.74 ab
2 YAT		
H0	64.50 ± 4.71 a[4]	51.33 ± 8.10 c
H1	58.08 ± 4.55 abc	66.67 ± 7.26 ab
H2	50.42 ± 4.03 c	69.67 ± 6.28 a
H3	59.92 ± 4.84 ab	55.00 ± 7.58 bc
H4	61.83 ± 5.08 ab	61.00 ± 6.75 abc
H5	60.33 ± 5.16 ab	59.67 ± 7.76 abc
H6	51.58 ± 2.80 bc	67.67 ± 6.74 ab

[1] H0: control; H1: hand-hoeing a 1-m radius around the seedlings one year after planting (YAP); H2: hand-hoeing around the seedlings one and two YAP; H3: foliar application of glyphosate to a 1-m radius around the seedlings one YAP; H4: foliar application of glyphosate around the seedlings one and two YAP; H5: both hoeing and foliar application of glyphosate around the seedlings one YAP; H6: both hoeing and foliar application of glyphosate around the seedlings one and two YAP
[2] Cultural treatment main effect was significant one and two YAT ($p \leq 0.05$).
[3] Means within the same column with different letters were significantly different ($p \leq 0.05$).
[4] Transformed (log) values were employed for mean separation. Nontransformed values were used for actual means.

sites, respectively. The mean percent of soil clay content was also significantly greater (9%) than that of the SPH plots. The mean soil electric conductivity (EC) of the SPH plots was significantly greater (nearly 3-fold) than those of the SPB and SPS plots. The latter two treatments did not differ significantly for EC (Table 3).

No significant difference was found between the SPB and SPH plots for soil acidity (Table 4). The soil of the SPS plots was significantly more acidic compared to the soils of the other two treatments. The soils of the SPB plots averaged significantly greater (>2-fold) P concentration than did those of the SPS plots. The K and Mg concentrations of the SPB and SPH plots were significantly greater (>4-fold and 2.5-fold, respectively) than those of the SPS plots. The former two SPs did not vary significantly for Mg. The mean soil P concentration of the SPB plots was significantly greater (>2-fold) than that of the SPS plots. The SPH treatment did not differ from either the SPB or SPS treatment in mean P concentration (Table 4).

4. Discussion

Site preparation methods are reported to equally enhance forest site conditions, specifically the chemical and physical condition of the soil, i.e. availability of moisture and nutrients, aeration, and drainage (Cardoso et al., 2020; Steele et al., 2021). When using mechanical SP, gains in seedling survival and growth often increase with the intensity of the SP (Löf et al., 2012). Tolay et al. (1984) reported that compared to less intense mechanical SP treatments, intensive SP including discing after raking, subsoiling, and then discing via a bulldozer substantially improved the afforestation success rate for maritime pine

Table 3. Effects of site preparation treatments (SP) on the mean (± standard error) soil organic matter (SOM), sand, silt, and clay content, and electric conductivity (EC) on maritime pine sites two years after treatment.

SP[1]	SOM[2] (%)	Sand[2] (%)	Silt[2] (%)	Clay[2] (%)	EC[2] × 103 (mS/cm)
SPB	6.09 ± 0.56 a	41.73 ± 1.37 b	34.15 ± 0.98 b	24.12 ± 0.63 b	0.027 ± 0.001 b
SPH	6.73 ± 0.70 a	37.60 ± 1.36 b	40.29 ± 1.14 a	22.12 ± 0.72 c	0.064 ± 0.006 a
SPS	2.82 ± 0.23 b[3,4]	47.78 ± 2.26 a	20.64 ± 2.16 c	31.59 ± 0.80 a[5]	0.020 ± 0.000 b

[1] SPB: Raking weeds and logging residue into windrows with no stump removal by bulldozer; SPH: SPB + foliar spraying with glyphosate SPS: standard treatment or tree stump removal + broadcasting ripping by the bulldozer.
[2] Site preparation main effect was significant ($p \leq 0.05$)
[3] Means within the same column with different letters were significantly different ($p \leq 0.05$)
[4] Transformed (log) values were employed for mean separation. Nontransformed values were used for actual means
[5]Transformed (square root) values were employed for mean separation. Nontransformed values were used for actual means

Table 4. Effects of site preparation treatments (SP) on the mean (± standard errors) soil acidity (pH) and macronutrient concentrations on maritime pine sites two years after treatment.

SP[1]	pH	P (ppm)	K (ppm)	Mg (ppm)
SPB	5.61 ± 0.06 a	9.83 ± 0.92 a	827.90 ± 56.61 a	82.42 ± 31.84 a[2]
SPH	5.59 ± 0.09 a	7.52 ± 1.34 ab	697.67 ± 73.16 a	79.47 ± 36.15 a
SPS	5.09 ± 0.26 b	4.69 ± 0.92 b	138.32 ± 35.99 b	22.43 ± 1.95 b

[1] Site preparation main effect was significant ($p \leq 0.05$)
[2] Transformed (ln) values were employed for mean separation. Nontransformed values were used for actual means

in Kerpe-İzmit, a location very close to the site of the present study. However, the present study showed that gains in seedling survival and growth in maritime pine depended on the intensity level of the SP treatment.

Highly intensive treatments such as subsoiling using a bulldozer equipped with rippers at a 0–60 cm soil depth followed by heavy discing were previously reported to have increased soil bulk density and clay content 8 YAT; however, reductions were observed in the total silt content, porosity, macropore space, and water-holding capacity of the soil (Hızal et al., 2007), all of which are vital for the distribution and growth of maritime pine (Barrio-Anta et al., 2020; Özel et al., 2021). The SBS of the present study is the standard SP treatment used by forest management in Turkey. In the present study, the SBS, as the most intensive treatment, had a significantly negative impact on early seedling performance and chemical and physical soil properties. This treatment dramatically reduced SOM, silt content, and most of the available nutrients in the soil. The SBS seemed to increase soil clay content. However, one should interpret the soil texture results with caution. A two-year period is a short period to see dramatic changes in soil texture as opposed to longer periods such as eight years after treatments (Hızal et al., 2007). Therefore, changes in soil texture specifically clay content may have resulted from simply site alterations in the plantation area rather than treatment effects. Also, it is well-known that soil clay content increases as one descends to the lower horizons (washing and accumulation zone). Since the fertile topsoil is stripped at a depth of about 10 cm in the weed clearing with the dozer blade in the SPB process, the topsoil samples taken from these plots perhaps represented the lower depth (10–20 cm) of the soil horizon, resulting in specifically the higher clay content for this treatment.

Polláková et al. (2021) reported that total porosity, aeration, and moisture capacity in the soil increased in parallel with silt content, whereas total porosity, macropore space, aeration, and moisture content declined with increased soil clay content. A soil content higher in silt with less clay could therefore partially explain the enhanced seedling growth and survival using the mechanical SP treatment with glyphosate application.

Highly intensive mechanical SP using frequent passes with heavy machinery such as bulldozers can also negatively impact soil and plant productivity by damaging the SOM, which is particularly crucial for many chemical and physical soil properties (Grigal and Vance, 2000) and the soil nutrient pool and bulk density (Fox, 2000; Yıldız et al., 2007, 2009). Yıldız et al. (2007, 2009) found a significant decrease in SOM, soil nutrients, and bulk density on mechanical SP sites compared to grubbing sites. Their purple rhododendron (*Rhododendron ponticum* L.) control study was carried out in Eastern beech (*Fagus orientalis* Lipsky) forests in Düzce, in the western Black Sea Region of Turkey, a location close to that of the present study. They also reported that the intensity (e.g., number of bulldozer passes on treated sites) of the selected SP treatment exacerbated the damage to soil bulk density.

Increasing the treatment intensity by adding a broadcast application of herbicide (SPH) to the basic SP treatment (SPB), on the other hand, improved seedling growth performance and vigor (i.e. less H/RCD) substantially throughout the present experiment without a significant improvement in seedling survival. The use of mechanical SP methods including herbicide application has been found to enhance the establishment and growth of fast-growing conifer species in plantations (Mohler et al., 2021) for slash pine (*Pinus elliottii* Engelm.) and loblolly pine (*P. taeda* L.) in the southeastern USA (Zao et al., 2008, 2009) and maritime pine in Europe (Varelides and Kritikos, 1995; Thivolle-Cazat and Najar, (2001). Mechanical SP integrated with herbicides is also reported to have successfully eliminated soil limitations and weed competition and therefore to have improved tree seedling growth in the Mediterranean countries (Löf et al., 2012).

One should, however, consider the herbicide phytotoxicity of young maritime pine seedlings carefully when using glyphosate applications (Cap and Eşen, 2018). In the present study, the maritime pine seedlings were shielded from the foliar application of 1% glyphosate to prevent herbicide phytotoxicity. On the other hand, if a direct application (i.e. without shielding) of this herbicide is used, it should be noted that the sensitivity of young maritime pine seedlings to foliar-applied glyphosate primarily depends on the rate and date of the application (Cap and Eşen, 2018). Glyphosate is not significantly phytotoxic to young maritime pine seedlings at <0.8%, whereas higher rates such as 1.2% are substantially phytotoxic to seedlings, regardless of the time of application. The sensitivity of maritime pine seedlings to glyphosate at intermediate rates such as 0.8% was reported to depend critically on the time of application. Glyphosate applications later in the growing season (i.e. May and June) are more phytotoxic to maritime pine seedlings (Cap and Eşen, 2018). As this pine is a drought-tolerant species, this can be attributed to the decreased layer of the epicuticular wax in maritime pine, which determines the wettability of the needles, and to the herbicide sensitivity of these conifers as the growing season advances (Wang et al., 2015; Cap and Eşen, 2018).

In the present study, the lack of a significant SP × CT interaction effect indicated that the effect of CTs did not vary across different SP methods. In the study region, for industrial plantations with fast-growing tree species including maritime pine, hoeing around seedlings is recommended three times, twice, and once for one, two, and three YAT, respectively, in addition to the mechanical SP (Birler, 2009). However, the traditional CT that included hoeing by hand in a 1-m radius around seedlings one year after planting (i.e. once during the experiment) (H1) sufficed to enhance seedling survival, whereas other more intense and costly CTs provided no additional significant improvement in seedling survival or growth.

5. Conclusion

The effect of site preparation on seedling performance and soil properties depended on the intensity level of the site preparation. The most intense site preparation (SPS) included raking and then subsoiling the site using a bulldozer significantly reduced seedling survival and growth and deteriorated the physical and chemical properties of the soil, especially soil organic matter and nutrients, compared to the basic and intermediately intense SP treatments. The intermediate SP treatment (SPH) that comprised raking the site and then applying foliar glyphosate at a 1% rate while shielding the seedlings was the best overall in terms of seedling performance and physical and chemical soil properties one and two YAT. Hoeing in a 1-m radius around seedlings one year after planting (i.e. once during the experiment) (H1) significantly improved seedling survival and vigor compared to the control (H0). No additional gain in seedling survival or growth performance occurred in more intensive CT combinations. In summary, for maritime pine, hoeing at the end of the subsequent summer (H1) following the SPH is recommended for enhanced early seedling performance, soil productivity, and cost-efficiency.

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References

Alía R, García del Barrio JM, Iglesias S, Mancha JA, de Miguel J et al. (2009). Regiones de procedencia de especies forestales en España. OAPN, Madrid, ISBN 978-84-8014-759-0 (in Spanish).

Bağçaci SÇ, Yucel I, Duzenli E, Yilmaz MT (2021). Intercomparison of the expected change in the temperature and the precipitation retrieved from CMIP6 and CMIP5 climate projections: A Mediterranean hot spot case, Turkey, Atmospheric Research 256 (105576). doi: 10.1016/j.atmosres.2021.105576

Barrio-Anta M, Castedo-Dorado F, Cámara-Obregón A, López-Sánchez CA (2020). Predicting current and future suitable habitat and productivity for Atlantic populations of maritime pine (*Pinus pinaster* Aiton) in Spain. Annals of Forest Science 77 (41). doi: 10.1007/s13595-020-00941-5

Birler AS (2009). Industrial forest plantations. Düzce University Press, İstanbul, Turkey (in Turkish).

Bremner JM (1996). Nitrogen - Total. In: Sparks AL, Page PA, Helmke RH, Loeppert RH, Soltanpor PN et al. (editors). Methods of Soil Analysis, Part 3 Chemical Methods. American Society of Agronomy and Soil Science Society of America, Madison, Wisconsin, USA, pp. 1085-1121.

Cap MC, Eşen D (2018). Effects of application date and rate of foliar-applied glyphosate on young pine seedlings in Turkey. Journal of Forestry Research 29 (3): 583-591.

Cardoso JC, Burton PJ, Elkin CM (2020). A disturbance ecology perspective on silvicultural site preparation. Forests 11 (1278). doi:10.3390/f11121278

Cooling ENG (1977). Industrial Forestry Plantations, Turkey, Final Report, W.D. 28 UNDP/FAO, Rome.

Cortini F, Comeau PG, Boateng JO, Bedford L, McClarnon J et al. (2010). Effects of climate on growth of lodgepole pine and white spruce following site preparation and its implications in a changing climate. Canadian Journal of Forest Research 41: 180–194.

Eşen D, Yıldız O, Sargıncı M, Güneş N (2005). Ormancılıkta zararlı ot ilaçlarının kullanımı ve riskleri. A.İ.B.Ü. Ormancılık Dergisi 1 (2): 51-58. (in Turkish)

FAO (2019). Trees, forests and land use in drylands: the first global assessment – Full report. FAO Forestry Paper No. 184. Rome, http://www.fao.org/3/t7750e/t7750e0a.htm. [accessed on 01.11.2021].

Feng S, Fu Q (2013). Expansion of global drylands under a warming climate. Atmospheric Chemistry and Physics 13: 10081–10094.

Fernandes PM, Rigolot E (2007). The fire ecology and management of maritime pine (*Pinus pinaster* Ait.). Forest Ecology and Management 241: 1–13.

Fidan C (2017). Effects of organic matter content and seedling density for growing bare-root narrow-leaved ash (*Fraxinus angustifolia* vahl.) seedlings. Eurasian Journal of Forest Science 5 (2) : 87-93.

Fox RT (2000). Sustained productivity in intensively managed forest plantations. Forest Ecology and Management 138: 187–202.

Gee GW, Bauder JW (1986). Particle-Size Analysis. In: Klute A (editor). Methods of Soil Analysis, Part 1. Physical and Mineralogical Methods, Agronomy Monograph No. 9, 2nd Edition, American Society of Agronomy/Soil Science Society of America, Madison, WI, USA, pp. 383-411.

Grigal DF, Vance ED (2000). Influence of soil organic matter on forest productivity. New Zealand Journal of Forestry Science 30 (1/2) : 169-205.

Guignabert A, Delerue F, Gonzalez M, Augusto L, Bakker MR (2018). Effects of management practices and topography on ectomycorrhizal fungi of maritime pine during seedling recruitment. Forests 9 (5): 245.

Güner ŞT, Özel C, Türkkan M, Akgül S (2019). Türkiye'deki sahil çamı ağaçlandırmalarında ağaç bileşenlerine ait karbon yoğunluklarının değişimi (Changes in carbon concentration of tree components for maritime pine plantations in Turkey). Ormancılık Araştırma Dergisi (Turkish Journal of Forestry Research) 6 (2): 167-176 (in Turkish with an abstract in English).

Helmke PA, Sparks DL (1996). Lithium, sodium, potassium, rubidium, and cesium. In: Sparks AL, Page PA, Helmke RH, Loeppert RH, Soltanpor PN et al. (editors). Methods of Soil Analysis Part 3 Chemical Methods. American Society of Agronomy and Soil Science Society of America, Madison, Wisconsin, USA, pp. 551-574.

Hızal A, Zoralioğlu T, Zengin M (2002). Effects of different mechanized soil preparation methods on the survival and growth of *Pinus pinaster* (Aiton) industrial plantation at Kerpe-İzmit. In: Diner A, Ercan M, Goulding C, Zoralioğlu T (editors). Management of Fast Growing Plantations. Proceedings. International IUFRO Meeting. 11-13 September, İzmit, Turkey

Hızal A, Zoralioğlu T, Zengin M (2007). Changes in physical properties of fine-textured soils occurred within a rotation period of 21 years in *Pinus pinaster* (Aiton.) plantations established by mechanized soil preparation methods. Forestist 57: 43-59.

IPBES (2019). Summary for policymakers of the global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. In: Díaz S, Settele J, Brondízio ES, Ngo HT, Guèze M et al. (editors). IPBES secretariat, Bonn, Germany, pp. 1-3.

Kandemir A, Mataracı T (2018). Pinus L. In: Güner A, Kandemir A, Menemen Y, Yıldırım H, Aslan S et al. (editors), Illustrated Flora of Turkey 2. Nezahat Gökyiğit Botanical Garden Press, İstanbul, Turkey.

Karakaş A (2003). Kefken (TUR71/521) Ağaçlandırma Alanında *Pinus radiata* D. Don'un Gelişimi İle Toprak Özellikleri Arasındaki İlişkiler. Kavak ve Hızlı Gelişen Tür Orman Ağaçları Araştırma Enstitüsü Müdürlüğü Orman Bakanlığı Yayın No: 204, Müdürlük Yayın No: 237 Çeşitli Yayınlar Serisi No: 14, pp.64 (in Turkish).

Karamanoli K, Papaioannou A, Sofogianni S (2017). Soil fertility and productivity estimation of *Pinus pinaster* Aiton reforestations in Central and Northeast Chalcidice in Northern Greece. Journal of Forest Science 63 (10): 470–475.

Karaöz Ö (1989). Toprakların Bazı Kimyasal Özelliklerinin (Ph, Karbonat, Tuzluluk, Organik Madde, Total Azot, Yararlanılabilir Fosfor) Analiz Yöntemleri. İ.Ü. Orman Fakültesi Dergisi Seri B, 39 (3): 64–82 (in Turkish).

Kuo S (1996). Phosphorus. In: Sparks DL (editor). Methods of Soil Analysis. Part 3. SSSA Book Ser. 5. SSSA, Madison, WI, USA, pp. 869–919.

Le Maitre DC (1998). **Pines in cultivation: a global view. In:** Richardson DM (editor). Ecology and Biogeography of *Pinus*, Cambridge University. Press, Cambridge, pp. 407-431.

Löf M, Dey DC, Navarro RM, Jacobs DF (2012). Mechanical site preparation for forest restoration. New Forests 43:825–848.

Mohler C, Bataineh M, Bragg DC, Ficklin R, Pelkki M et al. (2021). Long-term effects of group opening size and site preparation method on gap-cohort development in a temperate mixedwood forest, Forest Ecology and Management 480 (118616). doi: 10.1016/j.foreco.2020.118616

Opio C, Jacob N, Coopersmith D (2000). Height to diameter ratio as a competition index for young conifer plantations in northern British Columbia, Canada. Forest Ecology and Management 137: 245-252.

Özel C, Güner ŞT, Türkkan M, Akgül S, Şentürk Ö (2021). Modelling the site index of *Pinus pinaster* plantations in Turkey using ecological variables. Journal of Forest Research 32: 589–598.

Polláková N., Šimanský V, Jonczak J (2021). The relationships of texture and hydrophysical properties in soil profiles under selected exotic trees in the context of climate change in Central Europe. Journal of Ecological Engineering 22 (6): 244-252.

Radosevich, S.R., Holt, J., Ghersa, C.M (2007). Ecology of Weeds and Invasive Plants.

Relationship to Agriculture and Natural Resource Management, 3rd Ed., John Wiley And Sons, Inc., New York.

Sánchez-Gómez D, Mancha JA, Cervera MT, Aranda I (2017). Inter-genotypic differences in drought tolerance of maritime pine are modified by elevated [CO_2]. Annals of Botany 120 (4): 591-602.

SAS Institute Inc. 1996. SAS / STAT users guide, version 6.12. SAS Institute, Cary, NC.

Steele JK, Aust WM, Seiler JR (2021). Effects of mechanical site preparation, planting stock, and planting aids on the survival and growth of American sycamore in a marginal old field riparian restoration. Forests 12 (1295). doi: 10.3390/f12101295

Suarez DL (1996). Beryllium, magnesium, calcium, strontium, and barium. In: Sparks AL, Page PA, Helmke RH, Loeppert RH, Soltanpor PN et al. (editors). Methods of Soil Analysis Part 3 Chemical Methods. American Society of Agronomy and Soil Science Society of America, Madison, Wisconsin, USA, pp. 575-601.

Thivolle-Cazat A, Najar M (2001). Evolution de la productivité et de la récolte du pin maritime dans le massif landais. Evaluation de la disponibilité future en Gironde.

Revue Forestière Française 3-4: 351-354 (in French).

Tolay U, Hızal A, Dönmez E (1984). Çeşitli toprak işleme yöntemlerinin Kerpe yöresindeki bozuk baltalıklarda ince tekstürlü toprakların fiziksel özellikleri ve ağaçlandırma başarısı üzerindeki etkileri. Poplar and Fast Growing Forest Trees Research Institute Annual Bulletin 18: 323-393 (in Turkish).

Tunçtaner K, Tulukçu M, Toplu F (1985). Investigation on the selection the origins of Maritime pine used in the industrial plantation in Turkey. Poplar and Fast Growing Forest Trees Research Institute Annual Bulletin 21:43-102.

Tunçtaner K, Tulukçu M, Toplu F (1988). Investigation on morpho-genetic characteristics and growth performance on the origins of Maritime pine. Poplar and Fast Growing Forest Trees Research Institute, Technical Bulletin 144: 120.

Tunçtaner K, Tulukçu M (1990). Growth performances of Cedar at the Species Trials in Marmara and Black Sea Regions of Turkey, International *Cedar* Symposium, Antalya.

Tunçtaner K, Daşdemir İ, Ertekin M, Özel HB (2012). Technical and Economical Evaluations of Maritime Pine Plantations in Western Black Sea Region of Turkey. Foresist 62: 31-45.

Turkes M, Turp MT, An N, Ozturk T, Kurnaz ML (2020). Impacts of Climate Change on Precipitation Climatology and Variability in Turkey. In: Harmancioglu N, Altinbilek D (editors) Water Resources of Turkey. World Water Resources, vol 2. Springer, Cham. pp. 467-491. doi: 10.1007/978-3-030-11729-0_14

Ürgenç S, Boydak M (1981). Hızlı gelişen Bazı Yabancı İğne Yapraklı Ağaç Türlerinin Türkiye'ye İthali ve Yetiştirilmesi İle İlgili Problemler (Issues with Importing and Cultivation of Some Fast Growing Exotic Coniferous Tree Species to Turkey), Türkiye'de Hızlı Gelişen türlerle Endüstriyel Ağaçlandırmalar Sempozyumu (Industrial Afforestation Symposium with Fast Growing Species in Turkey), 21-26 September 1981, Kefken, İzmit. Orman Genel Müdürlüğü Yayını, p. 157-170, Ankara (in Turkish).

Varelides C, Kritikos T (1995). Effect of site preparation intensity and fertilization on Pinus pinaster survival and height growth on three sites in northern Greece. Forest Ecology and Management 73: 111-115.

Wagner RG, Newton M, Cole EC, Miller JH, Shiver BD (2004). The role of herbicides for enhancing forest productivity and conserving land for biodiversity in North America. Wildlife Society Bulletin 32 (4) :1028–1041.

Walkley A, Black IA (1934). An examination of Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. Soil Science 37: 29–37.

Wang H, Shi H, Wang Y (2015). The wetting of leaf surfaces and its ecological significances. In: Aliofkhazraei M (editor) Wetting and wettability. Chapter 11. InTech Publ, Rijeka, pp 295–321.

Yildiz O, Sarginci M, Eşen D, Cromack JrK (2007). Effects of vegetation control on nutrient removal and *Fagus orientalis*, Lipsky regeneration in the western Black Sea Region of Turkey. Forest Ecology and Management 240 (1-3) : 186-194.

Yildiz O, Eşen D, Sarginci M (2009). Long-term site productivity effects of different

rhododendron control methods in eastern beech (*Fagus orientalis* Lipsky) ecosystems in the western Black Sea Region of Turkey. Soil Use and Management 25: 28-33.

Yıldız O, Eşen D, Sargıncı M, Çetin B, Toprak B (2022). Restoration success in afforestation sites established at different times in arid lands of Central Anatolia, Forest Ecology and Management 503: 119808. doi: 10.1016/j.foreco.2021.119808

Zhao D, Kane M, Borders B, Harrison M (2008). Pine growth response to different site-preparation methods with or without post-plant herbaceous weed control on North Florida's Lower Coastal Plain. Forest Ecology and Management 255: 2512–2523.

Zhao D, Kane M, Borders B, Harrison M (2009). Long-term effects of site preparation treatments, complete competition control, and repeated fertilization on growth of slash pine plantations in the flatwoods of the Southeastern United States. Forest Science 55 (5): 403-410.