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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 northern Africa, with a range exceeding 4 million ha (Alia et al., 2009; Sánchez-Gómez et al., 2017; Karamanoli et al., 2017; Kandemir and Mataraci, 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 Tuluğçu, 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., ...)
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; Özal 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 Najjar, 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 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 (40°58’13”N; 29°33’31”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 Sındırığı-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 (YAT) (i.e. once during the experiment), H2 which consisted of weeding and hoeing around seedlings one and two YAT (i.e. twice during the experiment), H3 that included the foliar application of glyphosate to a 1-m radius around the seedlings one YAT; H4 that used a foliar application of glyphosate around the seedlings one and two YAT (i.e. twice during the experiment), H5 that included both hoeing and foliar application of glyphosate around the seedlings one YAT, and H6 that combined both hoeing and foliar application of glyphosate around the seedlings one and two YAT (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 (P₂O₅) 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):

\[ \mu_{ij} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij}, \text{ where} \]

\[ \mu \text{ is the overall (grand) mean; } \alpha_i \text{ is the main effect of} \ SP \text{; } \beta_j \text{ is the main effect of} \ CT; (\alpha\beta)_{ij} \text{ is the interaction effect between SP and CT.} \]

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 ≤ 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 (>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 sites.

### 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.

<table>
<thead>
<tr>
<th>SP</th>
<th>RCD² (mm)</th>
<th>Height² (cm)</th>
<th>H/RCD²</th>
<th>Survival² (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 YAT</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SPB</td>
<td>6.15 ± 0.28 b</td>
<td>36.25 ± 1.44 c</td>
<td>60.3 ± 2.2 a</td>
<td>71.43 ± 3.83 a</td>
</tr>
<tr>
<td>SPH</td>
<td>9.80 ± 0.54 a</td>
<td>52.18 ± 1.54 a</td>
<td>55.6 ± 2.0 a</td>
<td>77.29 ± 3.76 a</td>
</tr>
<tr>
<td>SPS</td>
<td>9.68 ± 0.63 a&lt;sup&gt;4&lt;/sup&gt;</td>
<td>43.21 ± 2.14 b&lt;sup&gt;4&lt;/sup&gt;</td>
<td>46.4 ± 1.5 b&lt;sup&gt;4&lt;/sup&gt;</td>
<td>41.14 ± 2.79 b&lt;sup&gt;4&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>2 YAT</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SPB</td>
<td>11.35 ± 0.58 b</td>
<td>77.61 ± 2.22 c</td>
<td>71.7 ± 2.9 a</td>
<td>70.43 ± 4.16 a</td>
</tr>
<tr>
<td>SPH</td>
<td>20.84 ± 1.20 a</td>
<td>99.39 ± 2.29 a</td>
<td>50.7 ± 2.2 b</td>
<td>75.14 ± 3.89 a</td>
</tr>
<tr>
<td>SPS</td>
<td>18.56 ± 1.34 a&lt;sup&gt;4&lt;/sup&gt;</td>
<td>90.04 ± 3.19 b&lt;sup&gt;5&lt;/sup&gt;</td>
<td>51.9 ± 2.1 b&lt;sup&gt;5&lt;/sup&gt;</td>
<td>39.14 ± 2.76 b&lt;sup&gt;5&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>1</sup> 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.

<sup>2</sup> Site preparation main effect was significant one and two YAT (p ≤ 0.05).

<sup>3</sup> Means within the same column with different letters were significantly different (p ≤ 0.05).

<sup>4</sup> Transformed (square root) values were employed for mean separation.

<sup>5</sup> 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
in Kerpe-Izmit, 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 (Yatz), 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

### 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.

<table>
<thead>
<tr>
<th>SP</th>
<th>SOM (%)</th>
<th>Sand (%)</th>
<th>Silt (%)</th>
<th>Clay (%)</th>
<th>EC × 103 (mS/cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPB</td>
<td>6.09 ± 0.56 a</td>
<td>41.73 ± 1.37 b</td>
<td>34.15 ± 0.98 b</td>
<td>24.12 ± 0.63 b</td>
<td>0.027 ± 0.001 b</td>
</tr>
<tr>
<td>SPH</td>
<td>6.73 ± 0.70 a</td>
<td>37.60 ± 1.36 b</td>
<td>40.29 ± 1.14 a</td>
<td>22.12 ± 0.72 c</td>
<td>0.064 ± 0.006 a</td>
</tr>
<tr>
<td>SPS</td>
<td>2.82 ± 0.23 b</td>
<td>47.78 ± 2.26 a</td>
<td>20.64 ± 2.16 c</td>
<td>31.59 ± 0.80 a</td>
<td>0.020 ± 0.000 b</td>
</tr>
</tbody>
</table>

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 ≤ 0.05)  
3 Means within the same column with different letters were significantly different (p ≤ 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.

<table>
<thead>
<tr>
<th>SP</th>
<th>pH</th>
<th>P (ppm)</th>
<th>K (ppm)</th>
<th>Mg (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPB</td>
<td>5.61 ± 0.06 a</td>
<td>9.83 ± 0.92 a</td>
<td>827.90 ± 56.61 a</td>
<td>82.42 ± 31.84 a</td>
</tr>
<tr>
<td>SPH</td>
<td>5.59 ± 0.09 a</td>
<td>7.52 ± 1.34 ab</td>
<td>697.67 ± 73.16 a</td>
<td>79.47 ± 36.15 a</td>
</tr>
<tr>
<td>SPS</td>
<td>5.09 ± 0.26 b</td>
<td>4.69 ± 0.92 b</td>
<td>138.32 ± 35.99 b</td>
<td>22.43 ± 1.95 b</td>
</tr>
</tbody>
</table>

1 Site preparation main effect was significant (p ≤ 0.05)  
2 Transformed (ln) values were employed for mean separation. Nontransformed values were used for actual means
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 intermediate 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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