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RESEARCH

Effect of frequent clearcutting on some soil properties, temperatures, and herbaceous vegetation and the potential of their recovery in a short time

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Abstract Harvesting or degradation of forest ecosystems directly affects the microclimate, causing changes in air and soil temperatures and soil moisture in the forestlands. The objectives of this study were to investigate the effect of frequent clearcutting of forest cover on some selected soil properties, ambient and soil temperatures, soil moisture, and herbaceous vegetation cover and determine their recovery in a short period in the area subject to frequent clearcutting under the powerline corridors (PLCs). The study was conducted in the research forest of Istanbul University-Cerrahpaşa, Faculty of Forestry. The treatment plots were selected from the clearcut area, and control plots were selected from an untouched oak-hornbeam forestland. Soil temperature and moisture and maximum and minimum ambient temperatures were measured in the treatment and control plots between 2020 and 2021 and topsoil sampled between 2019 and 2021. Data were analyzed using analysis of variance (ANOVA) to test the effects of clearcutting on some selected soil properties in the short term after cutting. Clearcutting caused a significant increase in soil bulk density (BD) and a decrease in the soil total porosity (TP), soil hydraulic conductivity (HC), and saturation capacity (SC). Forest cover removal significantly decreased the soil organic matter (SOM) content by 3%, increased average soil temperature by 2.1 °C, and the difference between maximum and minimum temperatures by 8.8 °C. Additionally, clearcutting reduced the average soil moisture from 36 to 35%. The findings revealed that clearcutting negatively affected some hydro-physical soil properties and soil microclimate conditions that may not recover to their previous states within the next few years.

Keywords Clearcutting · Hydro-physical soil properties · Microclimate · Vegetation cover

Introduction

Along with the increasing global warming, the extreme conditions in the temperature and precipitation regime cause changes in the structure of forest ecosystems (Özkan & Gökbulak, 2017; Renaud & Rebetez, 2009; Zheng et al., 2000). This negative effect on the climatic parameters also causes some ecological changes in the vegetation cover and significantly affects the soil–plant-water relationship. This situation creates some differences in the resilience of the ecosystems to changes (Chen et al., 2020; Foote et al., 2015). It is important to know how replacing forest cover with herbaceous vegetation affects

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the hydro-physical properties of the soil and has an important impact on the soil's water budget and the herbaceous vegetation's growth performance.

The effect of forest cover on the microclimate is directly proportional to the presence of overstory and understory plant cover. Therefore, the forest cover creates a specific microclimate that is different from the regional climate of the region (Garduño et al., 2010; Redding et al., 2003). A modeling study carried out in Glasgow showed that a 20% increase in vegetation cover could reduce surface temperatures by 2 °C in 2050 (Emmanuel & Loconsole, 2015). In addition, vegetation also helps to improve soil fertility and aggregate stability, improve nutrient cycling, decrease runoff, and regulate infiltration and percolation (Hart & Chen, 2006; Maciel-Nájera et al., 2021).

On the one hand, the forest canopy allows less energy to reach the soil surface by reflecting solar beams and absorbing some direct solar radiation. Moreover, the above-ground biomass of the forest cover functions as a barrier decreases wind speed and increases soil moisture content, creating a better-growing environment with more suitable temperature and humidity conditions for plants. Radiation input increases on sunny days with clear sky conditions and air temperature increases more in open areas compared to forested areas during the daytime (Chen et al., 1999). In contrast to daytime, infrared radiation emission occurs at night from both the land surface and plants and is partially absorbed by the forest biomass. As a result, less cooling is observed during the night in forested areas compared to open spaces (Çepel, 1975; Özyuvacı, 1999).

The sustainability of soil functions plays an important role in maintaining ecosystem structure and function. That is, the soil provides the necessary moisture and nutrient conditions for plant growth (Dominati et al., 2010). It also provides direct or indirect service to the ecosystem thanks to the organic matter containing soil biomass. Removal of aboveground biomass typically affects the topsoil conditions firsthand. On the one hand, the removal of plant cover results in organic matter loss and causes increases in soil compaction, evaporation, soil temperature, and great daily changes in the temperature amplitudes (Özkan & Gökbulak, 2017; Robinson et al., 2009). It means that if the intensity of forestry practices cannot be well planned and the consequences of their results are not well understood, it can lead to many negative changes in the ecological conditions of the soil and hence productivity loss in the forest ecosystems.

As a result of both anthropogenic effects and forestry practices, there are losses in biodiversity and deterioration in soil quality. Increases in bulk density, especially those resulting from the pressure on the soil by ground-based harvesting machines such as bulldozers, are generally considered a negative effect of harvest and negatively affect site productivity (Bottinelli et al., 2014; Rab, 2004). Many studies have emphasized that clearcutting deteriorates the physical and chemical properties of the soil, causing a decrease in saturation capacity and porosity, and increases in soil erosion and forest degradation (Aytekin & Gökbulak, 2020; Guan et al., 2019; Hajabbasi et al., 1997). These degradations and changes cause an increase in invasive species and change plant species composition in the area. In addition, since invasive species are victorious in this competitive environment, the growth of the dominant species specific to the area is adversely affected. Generally, herbaceous species are more abundant in open areas where light and rainwater reach directly to the soil surface compared to forest areas (Germany et al., 2017; Wei et al., 2021). However, it poses a threat to these herbaceous plant species. They have higher extinction rates compared to other shrub and woody species (Gilliam, 2007). Several studies highlighted the role clearcutting plays in the spread of invasive species (Chen et al., 2020; Çoban et al., 2019; North et al., 2005).

The objectives of this study were to examine the effect of frequent clearcutting on the hydro-physical soil characteristics, soil and ambient temperatures, and determine the recovery degree of these parameters and herbaceous vegetation cover in the short term in a clearcut area located in the powerline corridors in the oak-hornbeam mixed forest area. We aimed to examine the effects of clearcutting on soil, plant, and microclimate properties that interact with each other in the ecosystem in general and determine how recovery takes place in a short period after vegetation removal.

Materials and methods

Study area

The study was carried out in the oak-hornbeam forest located within the Research Forest of Istanbul

University-Cerrahpaşa, Faculty of Forestry. It is located in the north of Istanbul and within the borders of the Belgrad Forest between 28°59′17″–29°32′25″ eastern longitudes and 41°09′15″–41°11′01″ northern latitudes (Fig. 1). The study site has an undulate topography with an altitude changing between 20 and 236 m and average slope of 25%. The average annual temperature and precipitation are 12.8 °C and 1111.4 mm, respectively. The climate is humid, mesothermal with a moderate water deficit in summer months, close to oceanic climate conditions according to the Thornthwaite climate classification method (climate type $B_3B_1'sb_1'$) (Demir, 2021).

The most common geological formation in the study area is the Neogene Formation, which generally consists of unhardened sand, clay, and loam layers. The study area's bedrock is clay schists, and the other bedrocks are Pliocene I/siltstone sediments mixed material, Pliocene I sediments, greywacke, sandstone, and andesite. The soil group is Luvisol, and the clay loam is usually in texture (IUSS Working Group WRB, 2022). Soils are generally shallow to deep, are rich in organic matter with medium to good permeability rates, and have no calcium carbonate reaction (Özhan, 1977).

Overstory vegetation is composed of oak species including *Quercus petrea* ssp. *iberica*, *Quercus cerris* var. *austriaca*, *Quercus robur*, and *Quercus frainetto* with a small portion of other tree species such as *Castanea sativa*, *Tilia tomentosa*, *Carpinus betulus*, and *Corylus avellana* (Ayaşlıgil, 1997) whereas understory vegetation mainly consists of *Hedera helix* L., *Ruscus hypoglossum* L., *Smilax excelsa* L. *Doronicum orientale* Hoffm., *Primula vulgaris* Huds., *Carex* sp., and *Fragaria vesca* L. species in the control plots. *Rubus* sp. and *Cistus* sp. are the shrub species predominantly found in the treatment plot. In addition, *Conyza canadensis* L. Cronquist, *Doronicum orientale* Hoffm., *Holcus lanatus* L., and *Poa annua* L. are the most common herbaceous species in the treatment plots.

Experimental design

The sampling area was located in a mixture of oak-hornbeam forest within the boundaries of the Research Forest of Istanbul University-Cerrahpaşa, Faculty of Forestry (Fig. 1). Powerlines pass throughout the forestland, and forest vegetation underneath is removed with a rotation period of 20 years. This practice involves cutting down trees that are likely to come into contact with powerlines and completely removing above-ground vegetation to protect the area under powerlines against negative situations such as fire. The trees under the powerlines were clearcut in June 2019 followed by bulldozer piling and created an open strip with a width varying between 30 and 50 m. Since the vegetation cover consists mostly of shrubs, it cannot be used as merchantable timber or recycled. Therefore, some of the harvest residues were left on

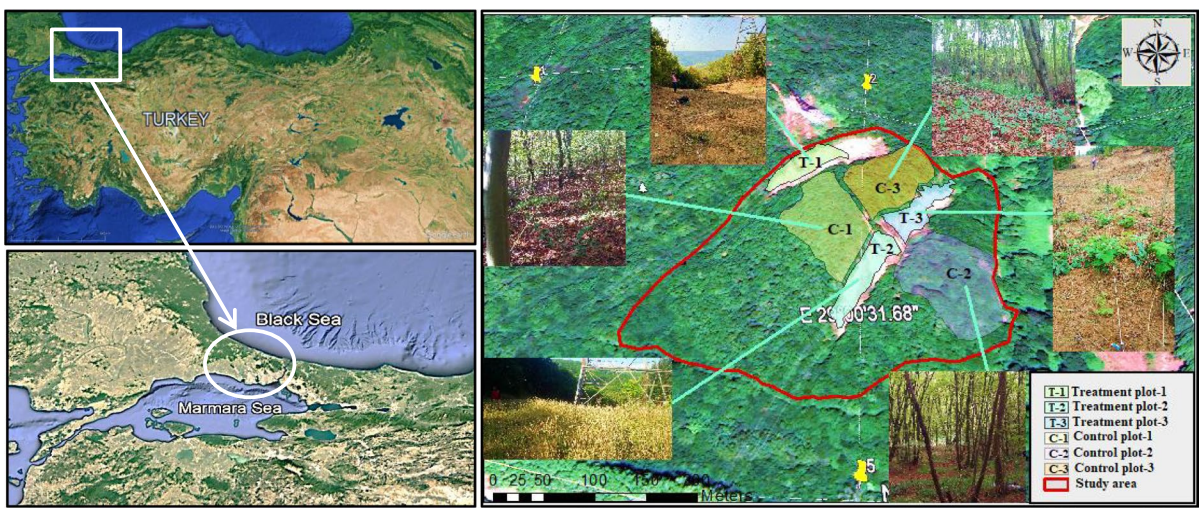


Fig. 1 Location of the study area and treatment plots

the field, while some were removed against the fire risk.

The experiment was completely randomized design with three replications. The treatment plots were selected from the area where the clearcutting was performed and plant residues were also removed from the soil surface to eliminate wildfire risk, while control plots were selected from the untouched oak-hornbeam forest area immediately adjacent to the treatment plots. Each plot had a size of 20 by 40 m and was divided into 2 × 2 m grids to determine sampling points. During each sampling, soil sampling was carried out at 10 randomly chosen grids for each plot. Since the topsoil is the most affected part by harvesting activities, disturbed and undisturbed soil samples were taken from 0 to 10 cm soil depth. Soil sampling was immediately after vegetation clearance in October 2019, 1 year later in October 2020, and 2 years later in October 2021. This process yielded 180 soil samples acquired from a combination of land uses, replicates, and periods (2 land uses × 3 replicates × 3 periods × 10 soil samples = 180 samples).

Soil temperature and moisture content were also recorded in the treatment and control plots. Soil temperature, soil moisture, and maximum and minimum air temperatures were recorded every week around noon at the same time on the same day between 2020 and 2021. Soil temperature was recorded at the soil depth of 10 cm using digital thermometers during every field visit. Soil moisture was also measured at the same locations, where soil temperature was measured, using the Bouyoucos BN-2B model moisture meter with gypsum blocks (Bouyoucos & Mick, 1939; Johnson, 1962). Gypsum blocks were placed into the soil at a depth of 50 cm in each sampling plot, and soil moisture measurements were carried out at the same time when the soil temperature was made. Air temperature and maximum and minimum air temperatures were recorded using digital thermometers placed in the treatment and control plots. Air temperature measurements were conducted at the same time as soil temperature and moisture measurements.

Soil samples were air-dried, grounded, and sieved through a 2-mm sieve to analyze for soil texture, soil fractions, dispersion ratio (DR), soil particle density (PD), soil bulk density (BD), total porosity (TP), pH, electrical conductivity (EC), loss on ignition (LOI), soil organic matter (SOM), saturation capacity (SC), hydraulic conductivity (HC), field capacity (FC), permanent wilting point (PWP), and available water capacity (AWC). Some hydro-physical properties of the soil, such as soil texture, DR, PD, and BD, were analyzed based on the methods explained by Özyuvacı (1976) as follows: Soil texture and DR were determined using the Bouyoucos hydrometer method and PD using the pycnometer method. BD was estimated by dividing the mass of the soil core content by the core volume and some other soil characteristics were analyzed as follows. TP was estimated according to the relationship between the soil particle density and the soil bulk density as explained by Özhan (2004). Soil pH and EC were determined on the samples with a soil–water ratio of 1:5 using a WTW Multiline P4 Universal Meter (WTW, Weilheim, Germany). LOI was calculated as a percentage of the oven-dried soil sample weight after the soil samples were ignited at 600 °C for 3 h (Howard & Howard, 1990) and OM content was determined by the Walkley Black wet digestion method (Gülçur, 1974). HC was determined according to Darcy's law equation (Özhan, 2004). Moisture contents of the soil samples at FC and PWP were determined after applying 1/3 atm and 15 atm pressures to the soil samples, respectively. AWC was estimated as the difference between moisture percentages of the samples at the field capacity and permanent wilting point (Huntington, 2007).

Vegetation characteristics

To identify plant species that appeared in the plots after the treatment and determine their density, frequency, and aerial cover, understory herbaceous vegetation was monitored during the vegetation period between March and October on the three 25-m long permanent transect lines randomly placed in each plot for the years 2020 and 2021. Vegetation measurements were carried out by using a quadrat with a size of 0.5 × 0.5 m. The quadrat was randomly placed on the or left side of the transect line with 2-m intervals. The plant species within the quadrat and their numbers were recorded and then their density and frequency were estimated. The percentage of vegetation cover in the quadrate was visually estimated and recorded as explained by Gökbulak (2013). Shannon's diversity index was used to determine species richness (Gökbulak, 2013; Xu et al., 2022; Zhao et al., 2021).

$$H\prime = -\sum_{i=1}^{k}\left(p_i \log p_i\right),$$

where H' = Shannon's diversity index, k = the number of species, and p_i = the proportion of observations in the category i.

Data analysis

Data was analyzed by using one-way ANOVA. The Kolmogorov–Smirnov test was applied to the data to check the normality before the analysis of variance. If data were not normally distributed, arcsine, logarithmic, or square root transformations were applied depending on the data types (Zar, 1996). The difference between means was compared with the Tukey test ($P < 0.05$). Jamovi 2.3.21 and SPSS Statistics 23.0 program were used for the statistical analysis of the data (The Jamovi Project, 2023).

Results and discussion

The impacts of vegetation removal on soil temperature, soil moisture, and ambient temperatures

The clearcutting caused significant changes in soil temperature, soil moisture, and maximum and minimum air temperatures ($P < 0.05$) (Table 1). Results showed that a 2.1 °C increase occurred in soil temperature, 7.7 °C in the air temperature, 6.9 °C in the average monthly maximum air temperature, and 8.8 °C in the difference between maximum and minimum temperatures after clearcutting. However, there was a 1% decrease in soil moisture and 1.9 °C in average monthly minimum air temperature (Table 1). In general, there were variations in the soil temperature trend (Fig. 2a). Zhang et al. (2018) monitored the changes in soil temperature and moisture after light, moderate, and intensive silvicultural applications and found that there were temperature increases of 7.8% in the light, 5.6% in the moderate, and 16.1% in the intensive silvicultural applications due to the reduction of the tree layer. Average soil temperature showed significant increases between March and early November and decreases in the period between the end of December and the beginning of February in the treatment plot (Fig. 2a). This situation can be attributed to the decrease in vegetation cover. For instance, Hashimoto and Suzuki (2004) monitored soil temperature in years 1994 and 2000 in Japan and found that clearcutting caused the highest increase in average soil temperature at the topsoil. They concluded that clearcutting caused an increase in the average soil temperature in summer and a decrease in winter months. The findings of their study are consistent with the results of our study that higher temperatures in summer and lower temperatures in winter months were recorded in the treatment compared to the control plot.

Although the soil moisture content of the treatment and control plots followed a similar trend (Fig. 2b), clearcutting resulted in a 1% decrease in soil moisture of the soils in the treatment plot. The average soil moisture value in the treatment plot was 35% and varied from 24 to 47% whereas it was 36% in the control plot and showed changes between 22 and 48% (Table 1). Similar to our findings, Miah et al. (2014) reported that clearcutting caused a decrease in soil moisture due to increased evaporation. In contrast, Aytekin and Gökbulak (2020) compared the moisture content of the soils in the forestland with that of open space and reported that forest soils had a higher moisture content than the soils of the open area. The result of that study was not consistent with the result of our study. This difference may be attributed to the

Table 1 Mean values (mean ± SD) of selected microclimate parameters for treatment and control plots

Microclimate parameters	Treatment plot	Control plot
Soil temperature (°C)	$17.40^{a*} \pm 2.98$	$15.30^{b} \pm 1.33$
Soil moisture (%)	$35.26^{a*} \pm 5.71$	$36.33^{b} \pm 6.41$
Average monthly air temperature (°C)	$28.04^{a*} \pm 9.18$	$20.34^{b} \pm 4.03$
Average monthly maximum air temperature (°C)	$29.80^{a*} \pm 3.65$	$22.90^{b} \pm 1.72$
Average monthly minimum air temperature (°C)	$7.60^{a*} \pm 2.04$	$9.50^{b} \pm 1.94$
Difference between mean monthly maximum and minimum air temperatures	$22.20^{a*} \pm 4.86$	$13.40^{b} \pm 2.50$

*Different superscript letters differ significantly at the same row ($P < 0.05$)

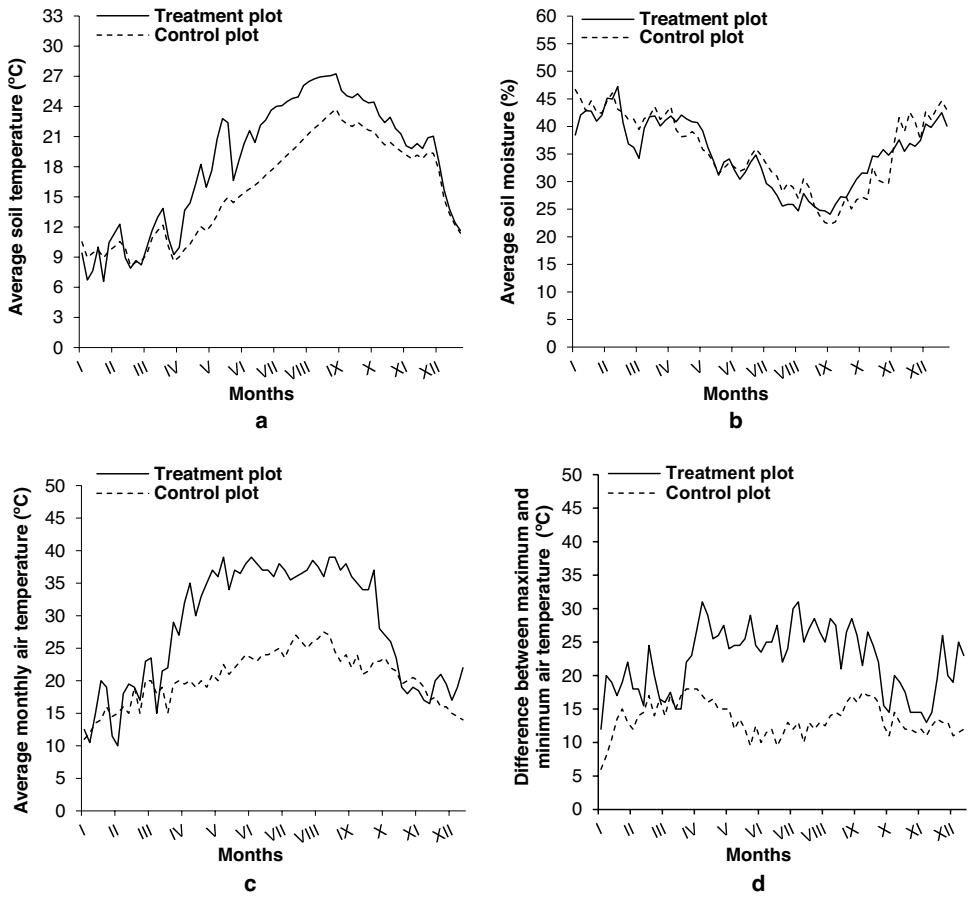


Fig. 2 Trend of soil temperature (**a**), soil moisture (**b**), air temperature (**c**), and difference between maximum and minimum air temperatures (**d**) in the treatment and control plots

soil surface conditions after clearcutting. They studied in an open area that had long been clearcut with accumulated forest litter from the adjacent forest area and existing growing herbaceous vegetation. It could be the result of rainfall interception by forest litter and moisture consumption of herbaceous vegetation from the topsoil in the forest land. Thus, it can be concluded that both processes may have affected the amount of soil moisture in the topsoil (Özkan & Gökbulak, 2017). In contrast, Yildiz et al. (2011) investigated the impact of vegetation removal on soil properties and did not find any changes in the moisture content of the soil after the treatment.

Results showed that timber removal caused significant increases in the average monthly air temperature and average monthly maximum air temperature and significant decreases in average monthly minimum air temperature in the treatment plots ($P < 0.05$, Table 1). As seen from Table 1, air temperature and maximum temperature were found to be higher, and minimum air temperature was found to be lower in the treatment plot compared to the control plot. Similarly, Radler et al. (2010) found the average daily maximum air temperature measured in the clearcut was 2.5 °C higher and the average daily minimum temperature was 0.5 °C lower than in the forest. The differences between maximum and minimum air temperatures in the treatment plot showed greater variations and were higher especially in the winter months than those in the control plot. This difference can be attributed to the absence of a canopy of woody vegetation in the treatment plot. In contrast, the forest and shrub canopy functioning as a shelter prevented energy loss, and hence, temperature decreases in the control

plot. Since the atmosphere of the clearcut area was exposed to the sun directly without any shelter such as forest canopy, higher temperatures were recorded generally in the summer period in the treatment plots (Fig. 2c).

Additionally, the difference between the average monthly maximum and minimum temperatures showed significant increases in the treatment plot and decreases in the control plot during the summer months (Fig. 2d). It was seen that forest cover significantly reduced temperature differences (Ehbrecht et al., 2019). Similarly, Kubin and Kemppainen (1991) observed a similar change in the air temperature caused by forest cover. Their results were consistent with our results that clearcutting increased maximum air temperatures and decreased minimum temperatures in the treatment plots.

The impacts of vegetation removal on some selected soil properties

Clearcutting significantly affected the amount of soil fractions with diameters between 2 and 5 mm, sand, DR, PD, BD, TP, pH, LOI, SOM, SC, HC, FC, PWP, and AWC of the soils ($P < 0.05$). At the same time, it did not have any significant effect on the percentages of silt and clay particles and the amount of soil fractions smaller than 2 mm in the soils of the treatment plot ($P > 0.05$, Table 2). On the other hand, the amount of soil particles with a diameter between 2 and 5 mm was significantly decreased due to treatment but increased over the years and became similar to that in the control plot 2 years after the vegetation removal (Table 2). A decrease in the amount of soil particles with a diameter of 2–5 mm was found due to the bulldozer crushing the soil particles and breaking them into smaller pieces during cutting.

The DR significantly increased from 19.6 to 48.5 and reached 63.8 at the end of the study. Since dispersion ratios were greater than 15 (Özhan, 2004), the erodibility of the soils increased over time (Table 2) ($P < 0.05$). This means that clearcutting increased the soil's susceptibility to erosion over the years (Özhan, 2004). Similar to our results, Özhan (2004) reported a lower dispersion rate in the control plot compared to the treatment plot due to the higher amount of organic matter and clay content in the soils of the control plot. A similar result was reported by Shaw and Carter (2002) that the soils had a finer (due to high clay content) structure before the clearcutting but had a coarse structure (due to increased sand content) after the clearcutting and this structural change caused increased dispersion rate and susceptibility to erosion.

Soil pH increased significantly from 4.92 to 5.70 and did not show significant recovery over time. While the pH value was found to be higher in the treatment plot compared to the control plot over the years ($P < 0.05$), the EC value did not show any significant change due to clearcutting ($P > 0.05$). Similar to our findings, Miah et al. (2014) found a greater soil pH value in the cleared area than in the soils of the forest area. They suggested that this difference may be due to the accumulation of organic matter, which makes the forest soil more acidic than the cleared area. On the other hand, our result for EC was consistent with the result of Aytekin and Gökbulak (2020) that there was no significant difference between the electrical conductivity values measured in the forested area and the vegetation-cleared area. In contrast, Hajabbasi et al. (1997) found a significant decrease from 10 to 15% in the electrical conductivity values in the cleared area compared to the forest area.

SOM content of the soils significantly decreased from 4.10% (in the control plot) to 1.08% (in the treatment plot) and was less than 1% at the end of the study ($P < 0.05$). Similar to soil organic matter, soil LOI values also showed a significant decrease from 21.4 to 10.9%, and a significant reduction in the LOI was also observed at the end of the study (Table 2). Since litter and organic residues were removed together from the field with clearcutting, LOI and SOM decreased over the years. According to the results, it was observed that the absence of litter and organic residues affected the organic matter content of the soils. Additionally, while working with the bulldozer, the lower horizons were brought to the soil surface, causing a decrease in organic matter. The amount of organic matter is higher in the topsoil compared to the lower horizons of the soil (Özhan, 2004). The organic matter in the soil decreased by 85% and the loss on ignition decreased by 70% two years after clearcutting due to sheet erosion taking place on the bare soil surface conditions. These results were consistent with the results of studies conducted by other researchers (Chen et al., 2014; Zaman et al., 2010). For instance, Hajabbasi et al. (1997) found that the organic

Table 2 Mean values (mean ± SD) of physical and chemical soil parameters in three different periods under control and treatment plots

Soil properties	Land use	Year		
		2019	2020	2021
Sand (%)	Control	$62.2^{a*} \pm 3.62$	$66.2^{b} \pm 3.83$	$62.0^{a} \pm 3.49$
	Treatment	$65.7^{a} \pm 5.42$	$67.6^{ab} \pm 7.99$	$66.6^{ab} \pm 6.99$
Silt (%)	Control	$15.1^{a} \pm 2.13$	$13.8^{a} \pm 1.44$	$17.3^{a} \pm 3.58$
	Treatment	$14.6^{a} \pm 1.79$	$15.7^{a} \pm 2.86$	$15.8^{a} \pm 2.81$
Clay (%)	Control	$22.7^{a} \pm 3.43$	$20.0^{a} \pm 3.47$	$20.7^{a} \pm 1.82$
	Treatment	$19.7^{a} \pm 4.77$	$16.7^{a} \pm 6.14$	$17.6^{a} \pm 5.92$
Ø < 2 mm	Control	$91.0^{a} \pm 4.35$	$93.04^{a} \pm 2.26$	$94.42^{a} \pm 2.03$
	Treatment	$92.12^{a} \pm 5.34$	$94.40^{a} \pm 3.98$	$91.60^{a} \pm 3.87$
Ø between 2 and 5 mm	Control	$4.86^{a*} \pm 2.58$	$3.08^{b} \pm 1.41$	$3.53^{ab} \pm 1.61$
	Treatment	$2.38^{b} \pm 1.21$	$3.12^{b} \pm 1.75$	$5.55^{ca} \pm 2.25$
Ø > 5 mm	Control	$4.54^{a*} \pm 2.44$	$3.88^{a} \pm 1.80$	$2.05^{b} \pm 0.95$
	Treatment	$5.50^{a} \pm 4.77$	$2.48^{b} \pm 2.64$	$2.85^{b} \pm 2.03$
Dispersion ratio	Control	$19.6^{a*} \pm 7.05$	$24.1^{a} \pm 6.12$	$25.8^{a} \pm 6.09$
	Treatment	$48.5^{b} \pm 12.00$	$52.3^{b} \pm 11.10$	$63.8^{c} \pm 11.87$
pH	Control	$4.92^{a*} \pm 0.24$	$5.65^{b} \pm 0.41$	$5.45^{b} \pm 0.32$
	Treatment	$5.70^{b} \pm 0.55$	$6.33^{c} \pm 0.52$	$5.81^{b} \pm 0.37$
Electrical conductivity (µS/cm)	Control	$71.8^{a*} \pm 14.4$	$86.1^{a} \pm 21.9$	$89.4^{ba} \pm 17.4$
	Treatment	$60.1^{a} \pm 25.1$	$53.4^{ab} \pm 15.8$	$70.0^{a} \pm 21.4$
Organic matter (%)	Control	$4.10^{a*} \pm 1.15$	$4.34^{a} \pm 1.51$	$4.51^{a} \pm 0.70$
	Treatment	$1.08^{b} \pm 0.95$	$1.49^{b} \pm 0.94$	$0.59^{c} \pm 0.41$
Loss on ignition (%)	Control	$21.38^{a*} \pm 3.41$	$21.59^{a} \pm 2.87$	$20.37^{a} \pm 3.33$
	Treatment	$10.89^{b} \pm 2.59$	$9.27^{b} \pm 1.81$	$6.40^{c} \pm 0.52$
Hydraulic conductivity (mm/h)	Control	$752.2^{a*} \pm 902.3$	$1105.6^{a} \pm 1802.3$	$847.9^{a} \pm 697.3$
	Treatment	$79.6^{b} \pm 93.8$	$118.8^{b} \pm 209.4$	$73.5^{b} \pm 60.1$
Saturation capacity (%)	Control	$48.3^{a*} \pm 7.01$	$46.0^{a} \pm 9.42$	$48.6^{a} \pm 9.13$
	Treatment	$31.7^{b} \pm 5.02$	$28.7^{b} \pm 2.72$	$27.0^{b} \pm 4.49$
Bulk density (g/cm^3)	Control	$1.18^{a*} \pm 0.13$	$1.08^{a} \pm 0.12$	$0.98^{a} \pm 0.16$
	Treatment	$1.50^{b} \pm 0.16$	$1.49^{b} \pm 0.15$	$1.42^{b} \pm 0.09$
Particle density (g/cm^3)	Control	$2.25^{a*} \pm 0.07$	$2.13^{b} \pm 0.10$	$2.27^{a} \pm 0.09$
	Treatment	$2.44^{c} \pm 0.05$	$2.45^{c} \pm 0.11$	$2.53^{d} \pm 0.14$
Total porosity (%)	Control	$47.5^{a*} \pm 5.75$	$49.3^{a} \pm 6.33$	$56.8^{b} \pm 7.09$
	Treatment	$38.5^{b} \pm 7.33$	$39.2^{b} \pm 6.11$	$43.9^{a} \pm 4.45$
Field capacity (%)	Control	$30.1^{a*} \pm 3.84$	$32.7^{a} \pm 2.77$	$33.2^{a} \pm 3.80$
	Treatment	$22.5^{b} \pm 3.03$	$22.3^{b} \pm 1.87$	$20.4^{b} \pm 2.05$
Permanent wilting point (%)	Control	$17.7^{a*} \pm 3.73$	$20.9^{b} \pm 5.23$	$22.6^{b} \pm 4.42$
	Treatment	$13.5^{c} \pm 3.44$	$12.1^{c} \pm 2.80$	$13.3^{c} \pm 4.30$
Available water capacity (%)	Control	$12.4^{a*} \pm 2.86$	$11.8^{a} \pm 3.23$	$10.6^{a} \pm 3.82$
	Treatment	$9.0^{b} \pm 1.92$	$10.2^{b} \pm 3.50$	$7.1^{b} \pm 3.10$

*Different superscript letters differ significantly among years in the same row and between land uses for the same soil characteristic in the same year ($P < 0.05$)

matter content of the soils was greater in the forest area (2.5%) compared to the cleared area (0.97%). Similarly, Zhou et al. (2015) also reported that as a result of harvesting, there was a 44% decrease in the organic matter content of the soils compared to the forest area.

Soil HC values also showed a significant decrease from 752 to 79.6 mm/h after the harvest but 2 years after the treatment was not enough time for it to recover.

Moreover, significant decreases occurred in the soil SC from 48.3 to 31.7%, TP from 47.5 to 38.5%,

moisture at field capacity from 30 to 22.5%, PWP from 17.7 to 13.5%, and AWC from 12.4 to 9%. Contrary, soil BD significantly increased from 1.18 to 1.50 (g/cm^3) and soil PD from 2.25 to 2.44 gr/cm^3 ($P < 0.05$, Table 2). Among the soil characteristics affected significantly by the treatment, only soil fractions with a diameter between 2 and 5 mm showed significant recovery and returned to the level of the control plot. One year after cutting, perennial herbaceous vegetation and shrubs began to appear in the treatment plot. Since the soil surface is covered with vegetation, the soil will be more resistant to external factors such as rainfall. Therefore, with the decreased runoff, small particles will not be transported and soil fractions with a diameter between 2 and 5 mm may be preserved. The rest of the soil properties that were significantly affected by the treatment did not recover during the study period of 2 years (Table 2). Significant decreases in the soil TP, HC, and SC and increases in soil BD and PD can be evaluated as evidence of soil compaction and soil moisture reductions that occurred after clearcutting (Huntington, 2007; Zaman et al., 2010; Zhao et al., 2011).

When the changes in the soil characteristics in the treatment plots were examined over the years, the SC and HC values of the soil decreased over time after clearcutting, but these decreases were not found to be statistically significant between the years in the treatment plot ($P > 0.05$). On the other hand, the HC and SC values of the soil in the treatment plots were much lower than those of the control plot, and these significant differences between the control and treatment plots continued over the years ($P < 0.05$). In other words, there was no improvement in the HC and SC of the soil 2 years after clearcutting. The decrease in soil HC can be attributed to soil compaction caused by harvest machines during timber removal. It seemed that three rotations of the loader increased soil compaction and bulk density and decreased soil porosity. For instance, Reichert et al. (2018) reported that the topsoil was the most sensitive layer to compaction during the timber harvest. Bustos-Letelier et al. (2023) associated the bulldozer with the highest amount of soil compaction and bulk density among the four harvesting systems forwarder, tractor, bulldozer, and skidder. Additionally, greater soil bulk density after timber harvest can also be attributed to a decrease in the organic matter content of the soils. Our conclusion was supported by the findings of Zaman et al. (2010) that a decrease in the organic matter content of the soil in a deforested area caused soil compaction increase.

Although the decrease in the amount of TP was found to be statistically significant immediately after the treatment, it recovered to pre-treatment level at the end of the study ($P > 0.05$). Therefore, it can be said that 2 years after the timber clearance was enough for the soil TP to improve. In another study, a decrease was found in the soil's total porosity due to an increase in the soil bulk density in a clearcut area (Zhou et al., 2015). Moreover, high particle density in the soils can also be an indicator of soil compaction due to the removal of vegetation, which leads to a decrease in the total porosity of the soil (Guan et al., 2019; Muscolo et al., 2021; Zaman et al., 2010). The BD and PD of the soils increased after the treatment ($P < 0.05$), but they did not show a significant improvement over the years ($P > 0.05$) (Table 2). Lower BD and PD values in the control plot can be attributed to the higher amount of organic matter in the forest area. Undisturbed forest soil has high porosity and low soil bulk density and can be easily compacted by harvesting machines such as bulldozers. Working with a bulldozer in the treatment plot causes the soil profile to deteriorate and the organic matter on the soil surface to disperse (Rab, 2004). The result of our study was also consistent with the findings of Merino et al. (1998) that clearcut timber harvest increased the soil bulk density compared to that of the control area.

After the treatment soils' all FC, PWP, and AWC values significantly decreased ($P < 0.05$, Table 2) and did not recover over the 2 years. Soils in the control plots always had higher moisture content than those in the treatment plots. Due to the higher humus content, soils in the control plots located in the forest area had greater moisture content at the field capacity, permanent wilting points, and available water than that in the treatment plots located in the clearcut area ($P < 0.05$) (Balcı, 1996). Contrary to our findings, Zhao et al. (2011) reported that clearcutting did not significantly decrease the water content of the soils. In this respect, their conclusion was not consistent with the result of our study. Thus, it can be concluded that the water-holding capacity of the soils did not recover in 2 years.

Effects of vegetation removal on herbaceous vegetation

A total of 48 plant species were observed in the treatment plot and 26 species in the control plot. 42 plant species out of 48 species were herbaceous species and 6 species were shrub and woody species including oak and hornbeam seedlings. In the control plot, 19 herbaceous and 7 woody plant species including oak and hornbeam seedlings were observed in the control plant.

The dominant plant species was *Rubus* sp. with a density of 12.4 plants/m^2 while *Chondrilla juncea* L., *Calendula arvensis* (Vaill.) L., and *Galium odoratum* L. Scop were the least frequently observed herbaceous plant species with densities of less than 1 plant per square meter (0.4 plants/m^2). *Doronicum orientale* Hoffm was the most common plant species in the control plot with a density of 14.6 plants/m^2 while *Galium odoratum* (L.) Scop. was the least frequently observed species with a density of 0.4 plants/m^2. Kavgacı (2004) also studied plant populations in the same area and found that the Compositae family was the most dominant plant family with the most taxa in the area. The results of this study about plant species were consistent with the results of the study conducted by Kavgacı (2004).

The treatment plot had a greater vegetation cover (10.4%) than the control plot (8.9%) because tree canopy cover limited light intensity reaching the forest floor and forest litter prevented the regeneration of herbaceous plant species in the control plot (Dimov et al., 2015; Krzic et al., 2003). Therefore, understory vegetation cover and the number of herbaceous plant species in the control plot were less than those in the treatment plot (Fig. 3a). On the other hand, Chen et al. (2020) examined the effect of tree layers on species diversity and found that species richness decreased under the tree layer because of the shadow effect of canopy cover. However, contrary to our study, North et al. (2005) reported that there was a positive correlation between herb richness and litter depth. The most abundant plant species in the treatment plot was *Rubus* sp. with a vegetation cover of 43.38% whereas it was *Hedera helix* L. with a vegetation cover of 20.89% in the control plot. Due to favorable air and soil temperatures during the vegetation period, greater vegetation cover percentages were measured in the summer season in the treatment plot.

North et al. (2005) investigated the effect of soil moisture and light intensity on herbaceous and woody vegetation growth and found that there was a positive correlation between understory herb richness and soil moisture. The results of different studies were consistent with the results of our study that the removal of overstory vegetation cover increased the species richness in the area compared to the undisturbed control area (Bergstedt et al., 2008; Çoban et al., 2019; Yılmaz et al., 2018). Similarly, Battles et al. (2001) also reported that species diversity was higher in more open and bare lands, and species richness increased linearly with the intensity of silvicultural activities.

The results showed that clearcutting increased plant diversity (Fig. 3b). The average values of Shannon's diversity index were found to be 1.266 and

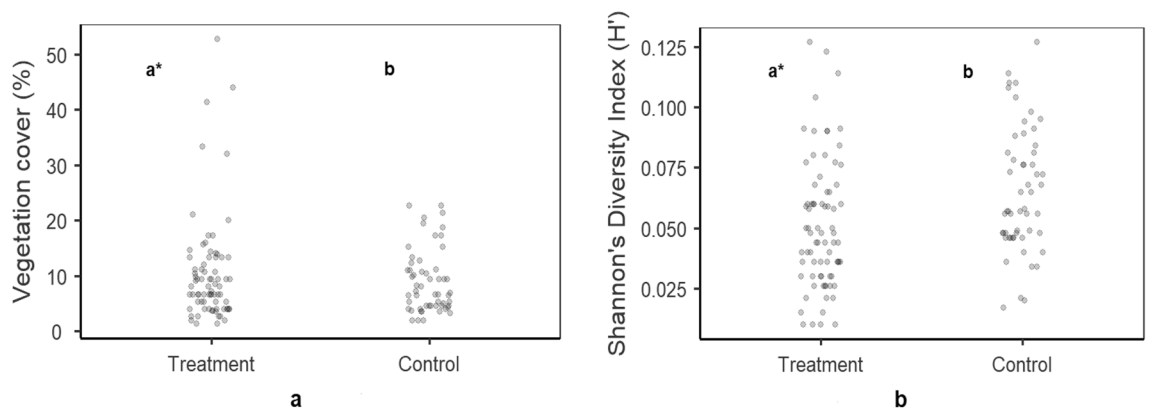


Fig. 3 Distribution of vegetation cover percentage (**a**) and diversity index (**b**) according to land uses

1.530 in the control and treatment plots, respectively. The diversity index value of herbaceous species was found to be higher in both land uses. In general, the average diversity indexes in the land uses showed a similar trend throughout the vegetation period.

Conclusions

This study was carried out to examine the effect of frequent clearcutting on some selected soil characteristics and determine if a 2-year period was enough time for their recovery. To examine the effect of clearcutting, soil sampling and measurements of temperature and soil moisture were carried out immediately after clearcutting, 1 year, and 2 years after the treatment. Our findings revealed that clearcutting caused significantly negative changes in the soil properties and temperature conditions. Significant decreases in soil porosity occurred as a result of soil compaction due to harvesting practices and this led to significant increases in soil properties such as BD and PD. On the other hand, the removal of vegetation cover and all plant residues from the field caused decreases in soil SOM and LOI. This situation appears to be closely related to the decrease in soil permeability, infiltration capacity, and water saturation capacity of the soil. Additionally, available water also decreased with the removal of the above-ground biomass from the field. On the other hand, results showed that a 2 year-period was not enough time for the recovery of the soil characteristics.

The results showed that forest ecosystems have an important impact on the microclimate of a site because of a 2.1 °C increase in mean soil temperature, an 8.8 °C increase in the difference between maximum and minimum temperatures, and about a 1% decrease in the available soil moisture determined after the treatment. The removal of forest cover caused increases in the summer temperatures and decreases in the winter temperatures because of the lack of forest cover in the treatment plot. Increased evapotranspiration from the treatment plot affected soil moisture content which in turn negatively influenced chemical, biological, and hydrological processes in the soils of the treatment plots. In this sense, this study also provided an understanding of the interaction between the vegetation change and the microclimate conditions. However, based on the result of this study, it is difficult to generalize the recovery of selected soil and climatic parameters after the clearcutting of forest cover because we monitored soil conditions and temperatures only for 2 years. To reach a better conclusion, long-term studies are needed to have a better understanding of the consequences of forestry activities in the ecosystems and make better management plans for environmental resources.

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Author contribution All authors contributed to the study's conception and design. Conceptualization, investigation and methodology were performed by all authors. Reyhan Sağlam was in charge of data collection and laboratory studies. The first draft of the manuscript was written by Reyhan Sağlam and Ferhat Gökbulak commented on previous versions of the manuscript. Writing, review, and editing were done by Ferhat Gökbulak. All authors read and approved the final manuscript.

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Data availability The data that support the findings of this study are available from the corresponding author upon reasonable request. Some of the data is included in Reyhan Sağlam's Ms. thesis. file:///C:/Users/Hp/Downloads/679528%20(1).pdf.

Declarations

Consent for publication The final version of the manuscript was reviewed and approved by all authors.

Competing interests The authors declare no competing interests.

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