SILVA BALCANICA

Silva Balcanica 25(2): 27-50 (2024)
doi: 10.3897/silvabalcanica.25.e121778

RESEARCH ARTICLE

Soils after forestry management activities in spruce plantations

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Academic editor: Ivaylo Velichkov | Received 27 February | Accepted 13 April 2024 | Published ?? June 2024

Citation: Kirova L. 2024. Soils after forestry management activities in spruce plantations. Silva Balcanica 25(2): 27-50. https://doi.org/10.3897/silvabalcanica.25.e121778

Abstract

The carbon accumulation in forest ecosystems helps to mitigate climate changes, therefore the interest in finding strategies for adapted forest management is a major goal of our time. The artificial plantations of Norway spruce (*Picea abies* Karst) are part of the Bulgarian project to restore the regulatory functions of forest ecosystems. Due to their low resistance, intensive processes of deposition and degradation take place in them, which emphasizes the need to understand the condition of soils and the amount of accumulated carbon in them. This paper reports results from a study on the thinning in even-aged Norway spruce plantations (*Picea abies* Karst) and its effect on some soil properties. The study includes two thinned plots and an untinned control: 1) Control – an unmanaged spruce plantation, without any activities in it through the last 20 years; 2) Thinned – managed with regular felling over the years, the last of which was carried out 10 years ago with 25% intensity; and 3) Ice storm – plantation damaged from an ice storm in 2007 (when it was 33 years old), felling followed by removal of all affected trees – over 95%, and afforestation with spruce saplings. The soil was examined by layers from 10 cm to 30 cm depth. The main soil characteristics connected with the carbon stocks in soil are analyzed - bulk density, skeleton, and carbon content. The results of the experiment show that the performed forestry activities were conducted with abidance of the requirements for habitat protection and the ecosystem's functionality in the studied sites. No significant changes in coarse fraction content and bulk density of soils were found. There is no statistical difference between the plots in the studied depths, but there is a trend of decrease in the organic carbon content in the managed sites. The differences in the soil carbon stocks are significant for the first two soil layers between the control and the managed trough thinning plot.

Keywords

carbon, coniferous, thinning, ice storm

Introduction

Forests constitute about 30% (4–5 billion hectares) of the earth's terrestrial area, providing many essential ecosystem services (Keenan et al. 2015). Soil carbon accumulation is the process of storing carbon in the form of organic matter in the soil. This process can provide various ecosystem services, such as: mitigating climate change by removing carbon dioxide from the atmosphere and reducing greenhouse gas emissions (Yasin et al., 2023); enhancing soil fertility by improving soil structure, water retention, nutrient cycling, and biological activity (Guo et al, 2019); supporting biodiversity by providing habitat and food for soil organisms and plants (Melillo et al., 2017). The multi-functionalities of soils and their role in ecosystem functioning has been an important scientific topic in Bulgaria as well (Todorova and Zhiyanski, 2023).

The major carbon storages in forest ecosystems are biomass and soils (Ciais et al., 2013; Zhiyanski, 2014; Stoeva, 2023). Temperate forests „play a significant role" in the global carbon cycle, considering that more than one-third of the carbon is stored in the vegetation and nearly two-thirds in the soil. The higher proportion (but lower level) in temperate forest soils (compared to tropical forest soils) is because of slower decomposition rates (Gorte, 2009). Many of these forests are managed to produce commercial wood products, and the management practices used in temperate forests can thus have a significant impact on carbon sequestration. Forest management is an activity that has economic importance for society but directly affects carbon stocks in individual carbon sinks. The different types of felling carried out in the forest territories are practices applied in the management of the forest territories (Regulations for the implementation of the forest law, 1999).

Forest thinning is a management practice that selectively removes trees to increase the availability of resources to the remaining trees to improve their growth and productivity (Nazari et al., 2022). Thinning regulates forest structure, reduces the risk of wildfires, enhances timber production, and increases forest resilience to environmental disturbances (Makinen and Isomaki 2004; Wang et al. 2019). Despite these benefits, some silviculture practices or disturbances could affect the soil organic carbon stock if the balance between the carbon inputs (for example from biomass residues or organic amendments) and the carbon losses (due to respiration, mineralization or leaching) is altered (Stoeva and Kirova, 2021). Thinning can lead to decreases in the soil carbon stocks due to reduced litter and root exudate inputs and increased rates of SOM mineralization (Zhang et al. 2018). Specifically, thinning increases the risk of C and nutrient limitations in coarse-textured soils of low fertility (e.g., Podzol) compared to fine-textured fertile soils (Page-Dumroese et al. 2010).

Coniferous plantations in Bulgaria are part of massive afforestation campaigns and are an important part of the Bulgarian work to restore the regulatory functions of forest ecosystems. Currently, most of these crops exceed 40-50 years of age, or they have only recently begun to reach maturity (Markoff et al., 2022). Due to their low resistance, intensive processes of deposition and degradation take place in them. Intensive successional processes have begun in the direction of restoring autochthonous vegetation (Popov et al., 2018). Science and practice should promptly react and anticipate the occurring natural processes, to utilize the accumulated wood mass, without ecological upheavals for the ecosystems. An attempt should be made to direct the natural biological processes in such a way as to obtain a smooth transition to a natural recovery of the most valuable and suitable tree species for the respective habitat (Popov et al., 2018).

Norway spruce (*Picea abies* Karst) is one of the most important species in the forests of the Alps, Carpathians, and the Balkan Mountains (Panayotov et. al, 2011). Apart from their key ecological role, these forests are very important for timber production and, in certain areas, for their protective functions against avalanches, rockfall, and soil erosion (Bebi et al., 2009).

The implementation of various forest management measures can lead to significant changes in the quantity, quality, and redistribution of organic matter in forest ecosystems (Guo & Gifford, 2002; Lorenz & Lal, 2005; Dannenmann et al., 2006). Direct removal of live woody biomass reduces total ecosystem C stocks (Amiro et al., 2006; Davis et al. 2009; Payeur-Poirier et al., 2011). The carbon stock in the living biomass depends to a great extent on the age structure of the plantations and their management (Stoeva, 2023). The management affects also the soil microclimate (Jassal et al. 2007). Logging with different intensities in the above changes the microclimate under the assembly and affects the temperature and humidity regime in the forest floor and soil, and hence indirectly on the resistance to soil processes (Saunders et al., 2012, Vesala et al., 2005, Piirainen et al., 2002). Studies on components of forest ecosystems show that changes in microclimate after logging correlate with increased rates of heterotrophic respiration and lower rates of autotrophic respiration (Ryu et al. 2009), thus CO_2 flux in total soil changes (Selig et al. 2008, Sullivan et al. 2008). It has been found that the change of carbon stocks in soils after thinning depends on the type of soil, climatic conditions, and tree species (Clarke et al., 2015).

The present study aims to determine the changes, or the lack of changes, in basic soil characteristics after forest management activities in spruce plantations from the territory of State Forestry Enterprise Botevgrad.

Materials and methods

Site Description

This study was conducted in 2020 in two forest sections, with a total area of 7.8ha, located in the west part of Stara Planina/Balkan Mountains in Bulgaria, on the territory of State Forestry Enterprise Botevgrad. The research area lies between 23°52′8″ E and 23°52′38″ E longitude and 42°54′18″ N and 42°54′29″ N latitude, at an altitude of 1130–1190 m above sea level. The study area is in the continental climate zone with an average annual rainfall of 51 mm and an average annual temperature of 10.46 °C (https://geotsy.com/bg/b-lgaria/botevgrad-69008/vreme-i-klimat). The soils in the studied fields are brown forest soils (*Cambisols*, WRB 2014). The silvicultural treatment applied in the study area was thinning with intensity between 20-25 % and sanitary felling, where it was needed.

Experimental Design

Three sampling plots have been set in spruce plantations (*Picea abies* Karst): 1) Control – an unmanaged spruce plantation, without any activities in it through the last 20 years; 2) Thinned – with regular felling over the years, the last of which was carried out 10 years ago with 25% intensity; and 3) Ice storm – plantation damaged from an ice storm in 2007 (when it was 33 years old), felling followed by removal of all affected trees – over 95%, reforestation with spruce saplings, and natural regrowth with local species.

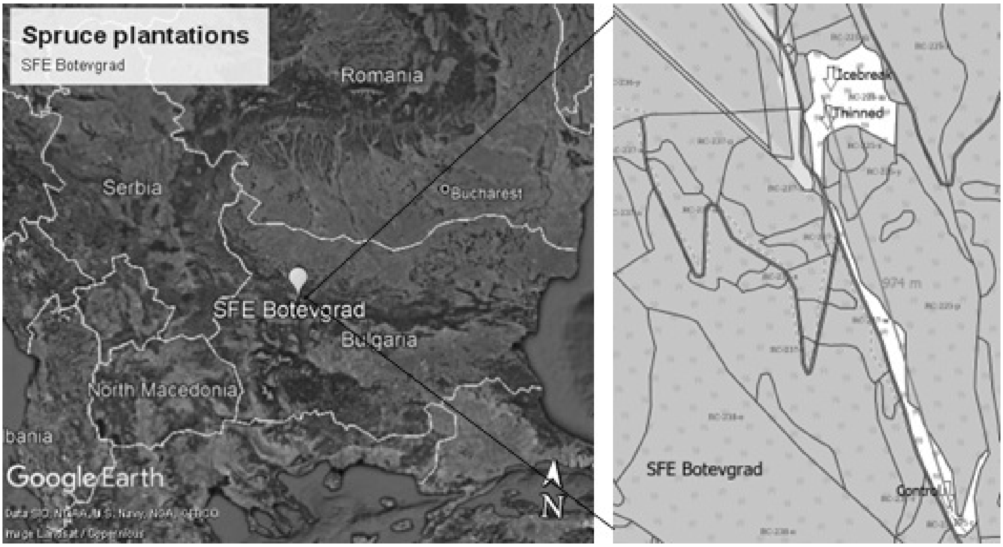

Figure 1. The study area in SFE Botevgrad in West Balkan Mountains, Bulgaria.

The environmental factors that have direct or indirect influence on the main soil characteristics are: the slope (D'Amore and Kane, 2016), the altitude and the aspect of the slope (Borissova et al., 2023). Thus, the three sample areas are chosen to have common characteristics of the habitat, listed in table. 1, and are closely located (Figure 1), which allows comparative analysis of the data obtained.

Table 1. Characteristics of the sampling plots

Sampling site	Soil type WRB 2014	Aspect of the slope	Altitude, m a.s.l.	Mean slope, º	Stand age (yrs)
Control	*Distric Cambisols*	NE	1186	21	45
Thinning		NE	1137	27	45
Ice storm		NE	1137	27	12

Each sampling plot is with a size of 0.1 ha. Soil samples were collected with an auger, covering all variations of the microrelief. The cylinder of the auger has a volume of 502.4 cm^3. The samples were collected in 5 replicates from depths of 0–10, 10–20, and 20-30 cm. They were stored and coded in plastic bags. On the same sampling day, the wet weight of all samples was measured.

Samples of forest floor were taken using a frame with dimensions of 25:25 cm, in five repetitions for all studied sites.

Measurements and Laboratory Analysis

In the laboratory, the soil samples were dried at 105 °C for 24 h to calculate the soil moisture content and dry bulk density. The forest floor samples were dried at 90 °C for 24 h to calculate the moisture content.

The bulk density and soil moisture were calculated using Equation (1) and Equation (2):

$$BD = \frac{WD}{VC} \qquad \text{Equation (1),}$$

where BD is the dry bulk density (g /cm^3), WD is the weight of the dry soil (g), and VC is the volume of the cylinder (cm^3).

$$W = \frac{(WW-WD)}{WD} * 100 \qquad \text{Equation (2),}$$

where W is the soil moisture (%), WW is the wet weight of the sample (g) and WD is the weight of the dry soil (g). The same equation is used for calculating the moisture content in the forest floor.

Total porosity of the soil was determined by a computational method from the relative and bulk density values (Donov et al., 1973) – Equation 3:

$$P = \frac{(1-BD)}{RD} * 100 \qquad \text{Equation (3),}$$

where P is the total porosity (%), BD is the bulk density and RD is the relative density.

The content of the coarse fragments was determined by weight method (Donov et al., 1973), which includes the following procedures: 1) a mean sample close to 100 g is taken from the dried soil sample; 2) it is weighted; 3) all the organics and soil is washed; 4) the residue is dried and sieved through 3 mm sieve; 5) all coarse fragments > 3 mm are measured and the content is calculated by Equation (4):

$$\mathrm{Cfr} = \frac{\mathrm{WCF}}{\mathrm{WMS}} * 100 \qquad \text{Equation (4),}$$

where Cfr is a fraction of coarse fragments > 3 mm (%), WMS is the weight of the mean sample (g) and WCF is the weight of the coarse fragments (g).

The mechanical composition of the soil was determined by Kaczynski's pipette method, in which the sample was treated with hydrochloric acid (Donov et al., 1973).

In order to measure the soil's chemical properties, soil particles <2 mm were used for the experiments. The HANNNA pH/ORP Meter (Model HI2211) was used to measure soil pH in a soil:water ratio of 1:5, and 1:4 forest floor:water ratio. The Tjurin method was used to determine the organic carbon (OC) content in percentage in the soil and forest floor samples - oxidation with a bichrome mixture K_2Cr_2O7/H_2SO_4 at a temperature of 160°C for 20 min with a pumice catalyst and silver sulfate Ag_2SO_4. Titrate with a 0.2N solution of Morr's salt $(NH_4)_2SO_4.FeSO_4.6H_2O$, with phenylanthranilic acid as an indicator, The Kjeldahl method was used to measure total N, for the soil and forest floor samples - ISO 11261. The C: N ratio was calculated. Organic carbon and total nitrogen stocks (Cstock and TNstock) were calculated following the GPG-LULUCF from IPCC (IPCC, 2003) and for the total nitrogen stock adapted by Ellert and Bettany (1995):

$$\text{SOC (or TN) Stock} = \text{Con. C or N (\%)} * \text{BD (g/cm}^3) * d\ \text{(cm)} * (1\text{-Cfr}) \qquad \text{Equation (5),}$$

where SOC (or TN) Stock = Soil organic carbon or nitrogen stock (t/ha^1); Con. C or N = Soil organic carbon or total nitrogen (%); BD = bulk density (g /cm^3); d = depth or soil layer (cm); and Cfr is a fraction of coarse fragments > 3 mm (%).

The forest floor carbon stock was calculated as the determined organic C content in g/100g multiplied by the dry weight of the sample per unit area (Shulp et al., 2008).

The data obtained from the analysis of the samples were statistically processed. The data are independent with a normal distribution (Shapiro-Wilk test), which allowed to perform t-test - one of the most widely used parametric tests to determine the distribution of probability variables and to draw conclusions about the distribution parameters (Kim, 2015).

Results

Forest floor

The mean forest floor stock is 57.06 t/ha in the control plot, 38.79 t/ha in the thinned plot, and 35.71 t/ha in the managed after ice storm plot (Fig. 2). There is no significant difference, but the trend is for decreasing of the quantities of the forest floor.

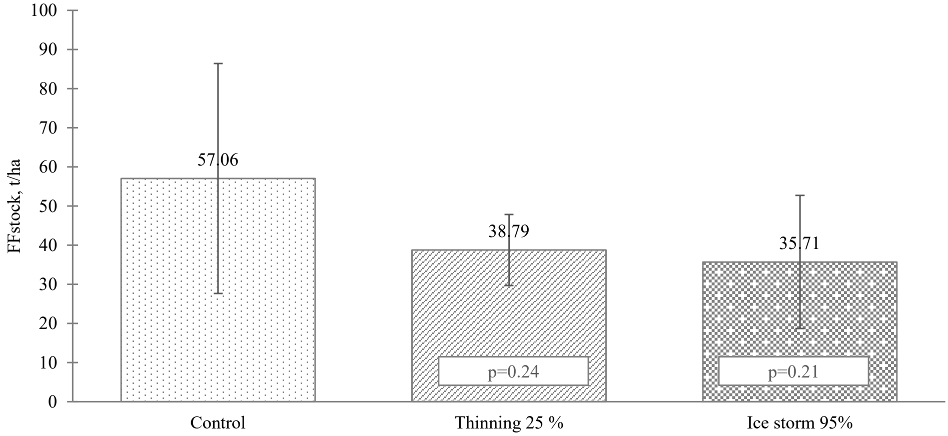

Figure 2. Average forest floor stock ± standard deviation, and p-value between the control and the studied plots

The observed water content in the forest floor layer is 7.88 % in the control plot, 27.10 % in the thinned plot, and 46.09 % in the plot damaged from an ice storm (Fig. 3). The variation has statistical difference and the trend is in increasing of the water content in the forest floor.

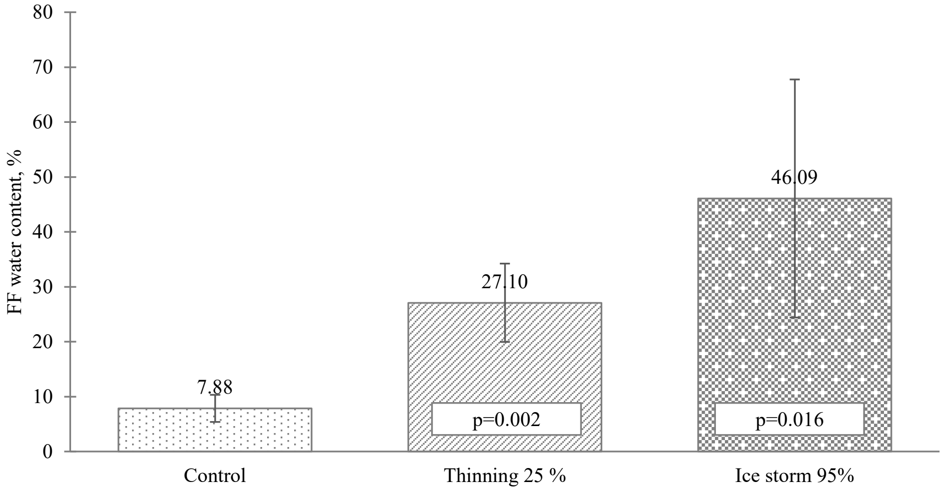

Figure 3. Average forest floor water content ± standard deviation, and p-value between the control and the studied plots

The observed average forest floor's reaction is acid and varies from 4.37 for the control plot, through 4.55 for the damaged from ice storm plot, and to 4.98 for the thinned plot (Fig. 4). The difference is significant between the control and the thinned plots and the reaction is still acid but higher in the managed site.

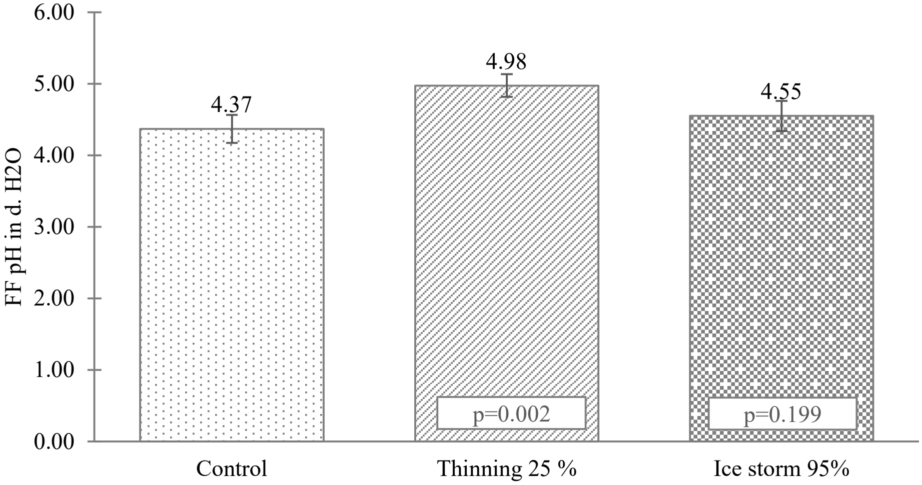

Figure 4. Average forest floor pH ± standard deviation, and p-value between the control and the studied plots

The mean of the measured organic carbon (C, %) in the forest floor for the control plot is 45.58 %, for the thinned plot – 35.54 %, and for the managed after ice storm plot – 44.40 % (Fig. 5). The difference is significant between the control and the thinned plots.

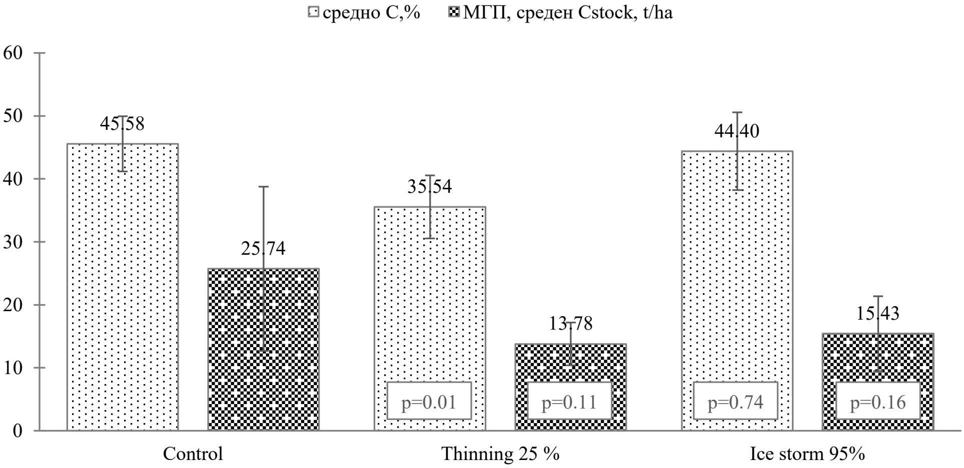

Figure 5. Average carbon content and Cstock in the forest floor ± standard deviation, and p-value between the control and the studied plots

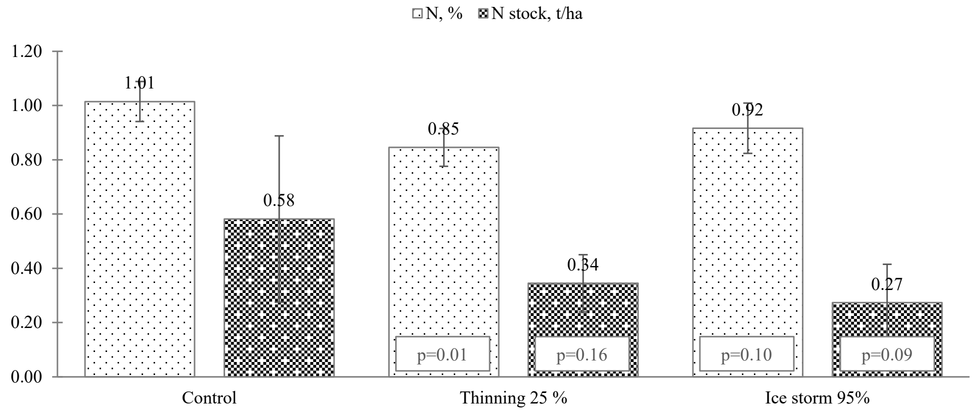

Figure 6. Average total N content (N) and Nstock in the forest floor ± standard deviation and p-values between the control and the studied plots

The average carbon stock (C_{stock}) of the forest floor in the control plot is 25.74 t/ha, in thinned – 13.78 t/ha, and in the damaged from ice storm plot – 15.43 t/ha (Fig. 5). The differences are not significant but there is a trend of decreasing of the carbon stock in the forest floor in the managed sites.

The mean of the measured total nitrogen (N, %) in the forest floor for the control plot is 1.01 %, for the thinned plot – 0.85 %, and for the managed after ice storm plot – 0.92 % (Fig. 6). The difference is significant between the control and the thinned plots.

The average total nitrogen stock (N_{stock}) of the forest floor in the control plot is 0.58 t/ha, in thinned – 0.34 t/ha, and in the damaged from ice storm plot – 0.37 t/ha (Fig. 6). There is significant difference, with p-value under 0.05, between the Nstock in the control and in the thinned plot.

The calculated C/N ratio for the forest floor is 44.90 for the control plot, 41.90 for the thinned and 48.35 for the damaged from ice storm plot. The obtained p-values shows no significant differences, for this parameter, between the control and the managed plots (Table 2).

Table 2. Average C/N ratio for the forest floor with standard deviation and p-values

	C/N	**Standard deviation**	**p-value**	**C/N, %**
Control	44.90	±2.03	-	-
Thinning 25 %	41.90	±3.06	0.111	Control vs Thinned
Ice storm 95%	48.35	±2.97	0.068	Control vs Damaged

Soil

Average soil bulk density on the control plot was measured as minimum 1.06 g/cm^3 to maximum 1.20 g/cm^3 and from 1.00 g/cm^3 to 1.45 g/cm^3 in the managed plots (Fig. 7). Soil compaction increased with the increasing of the depth, but no statistical difference was found between the different plots – p is above the significance level of 0.05.

The determined mechanical composition of the soil in the different layers is medium sandy loam (Table 3) with predominance of the sand fractions. The highest sand content is in the top soil layer in the thinned plot (70.71 %), where the soil mechanical composition type is slightly sandy loam considering Kaczynski's classification.

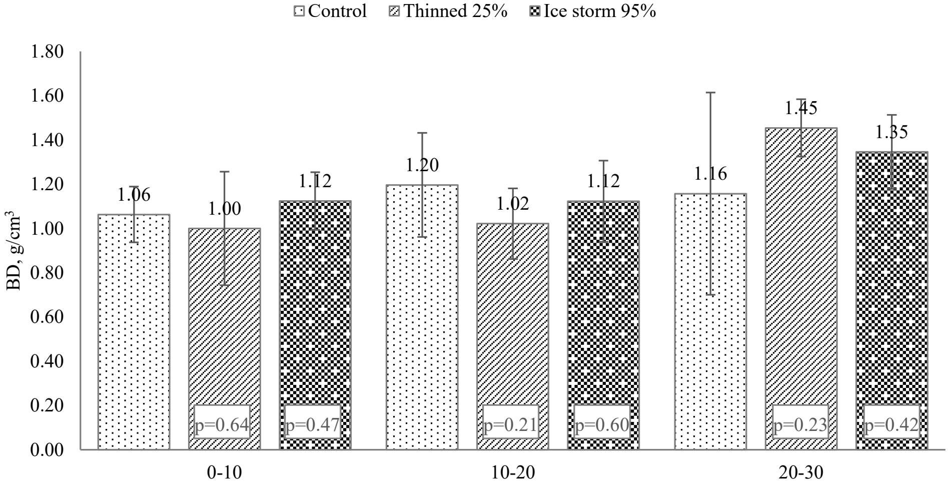

Figure 7. Bulk density/BD – average for the soil layer ± standard deviation, and p-value between the control and the studied plots

Table 3. Mechanical composition for the studied soil layers

Site	Layer, cm	Clay and Silt, %	Sand %	Soil mech. comp. type
Control	0-10	32,98	67,02	medium sandy loam
	10-20	30,95	69,05	
	20-30	36,35	63,65	
Thinned, 25 %	0-10	29,29	70,71	slightly sandy loam.
	10-20	37,81	62,19	medium sandy loam
	20-30	34,16	65,84	medium sandy loam
Ice storm, 95 %	0-10	38,21	61,79	medium sandy loam
	10-20	43,73	56,27	
	20-30	41,63	58,37	

Total soil porosity (P, %) was considerably lower in the damage from the ice storm site (Fig. 8). It increased by 23 % in the topsoil layer with increasing the intensity of the management and decreased by 32 % in the 20-30 cm layer. Porosity is inversely related to bulk density, meaning that a decrease in mean porosity comes with an increase in mean bulk density which is a weak trend in this study.

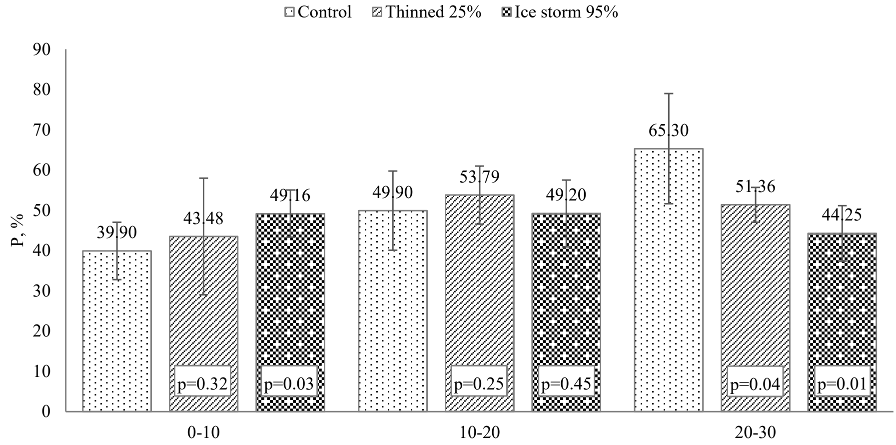

Figure 8. Soil total porosity (P, %) – average for the soil layer ± standard deviation, and p-value between the control and the studied plots

Soil moisture, on average, is from 12.64 % to 13.93 % on the control plot and lower in the managed sites for all studied layers (Fig.9). For the thinned plot observed soil moisture is between 10 % and 11 %, and for the damaged from an ice storm – between 4 % and 6 %. Soil water content was significantly decreased in the 10-20 cm layer, for the thinned plot (p=0.04), and in the managed after the ice storm plot (p=0.01).

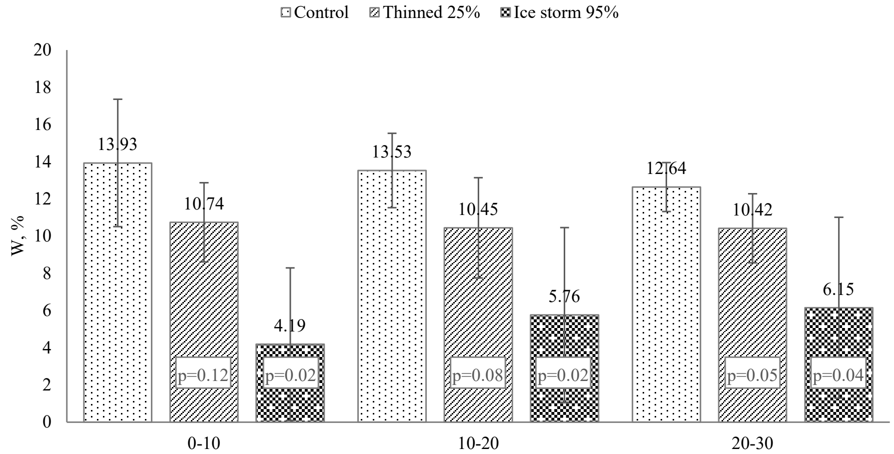

Figure 9. Soil moisture (W, %) – average for the soil layer ± standard deviation, and p-value between the control and the studied plots

Average coarse fraction content has been measured as 44-51 % on the control plot versus 57-65% in the thinned, and 51-60 % in the managed after ice storm plot. The observed skeletal content in the soil layers is highest in the surface 0-10 cm and decreases in depth (Fig. 10), without establishing significant differences between the three sample areas (p>0.05).

The observed soil reaction is acid in all studied plots, on average it varies between 4.49 and 4.80 (Fig. 11). There is no significant difference between studied layers or plots.

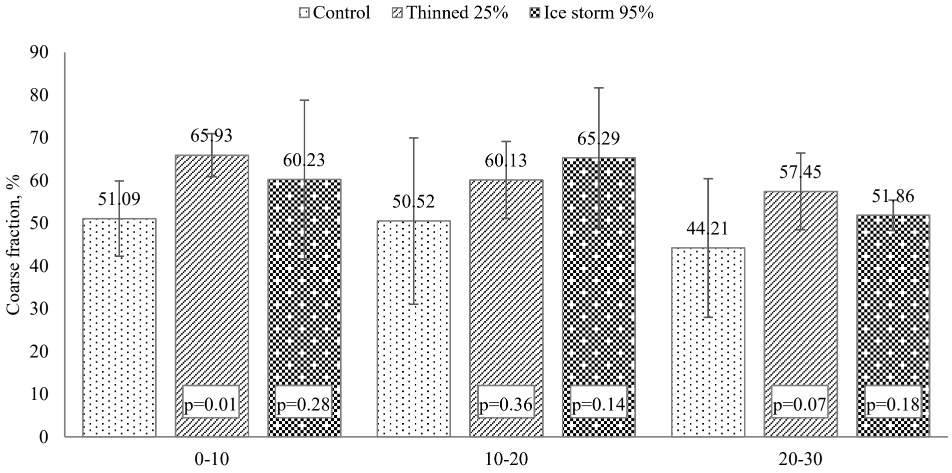

Figure 10. Coarse fraction content, % - average for the soil layer ± standard deviation, and p-value between the control and the studied plots

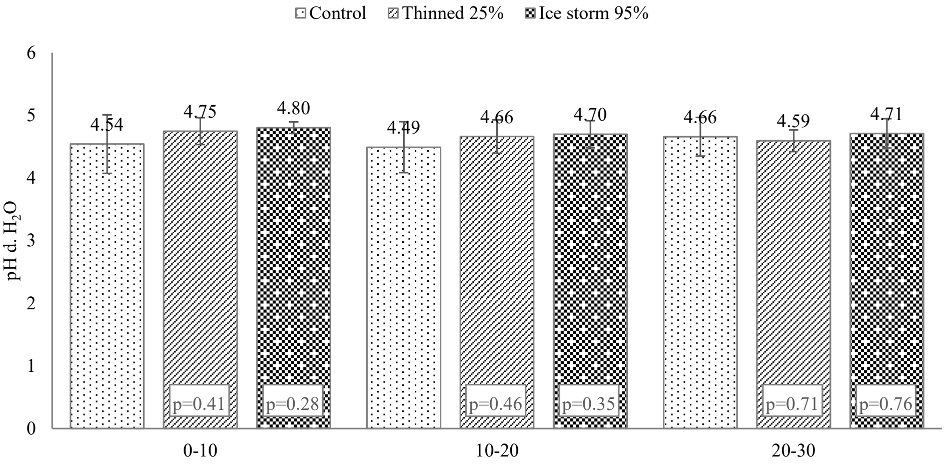

Figure 11. pH in distilled H2O – average for the soil layer ± standard deviation and p-value between the control and the studied plots

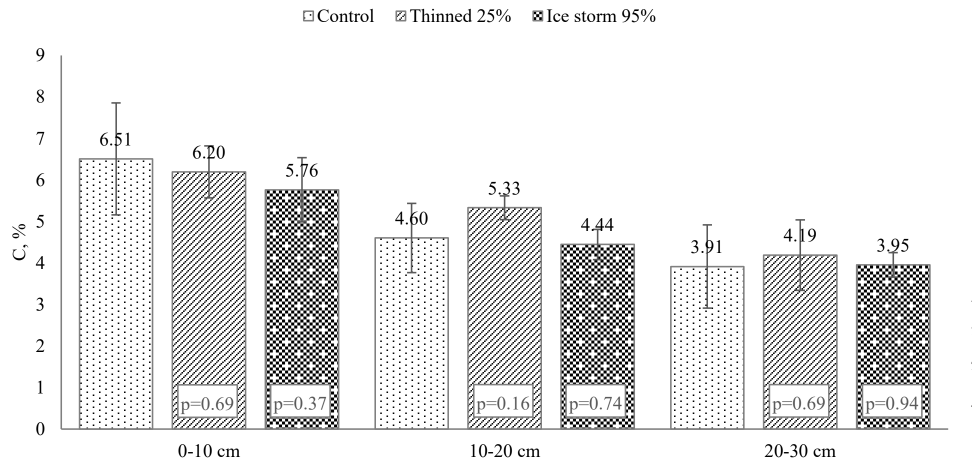

Figure 12. Average C content (C, %) in the studied soil layers ± standard deviation and p-value between the control and the studied plots

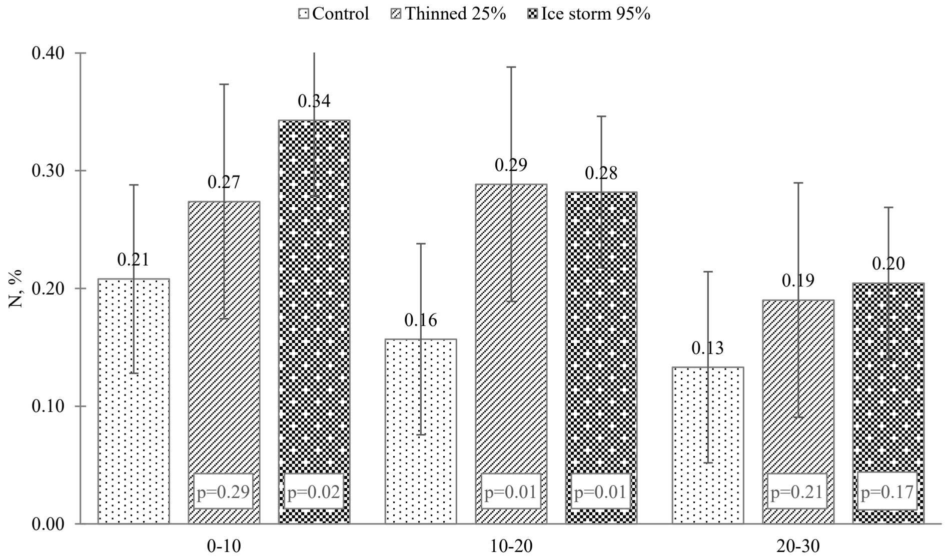

Figure 13. Average total nitrogen content (N, %) in the studied soil layers ± standard deviation and p-value between the control and the studied plots

Soil total nitrogen content was highest in the top soil layer for all studied plots, slightly decreasing in depth for the control – from 0.21 % in 0-10 cm to 0.13 % in 20-30 cm. For the thinned plot the content of total nitrogen is similar for the first two layers (0.27 and 0.29 %), and decreases in the last studied soil layer (20-30 cm –

0.19). In the damaged from ice storm plot, total nitrogen content is highest between the studied plots for all layers, starting from 0.34 % in the top soil, trough 0.28 % for 10-20 cm, and dropping to 0.20 % on the 20-30 cm layer (Figure 13). The results from the conducted t-test indicate that the difference between the control and the damaged plot is significant for the soil layers from 0 to 20 cm. The total nitrogen content in the thinned with intensity of 25 % plot differs significant from the control plot in the 10-20 cm layer.

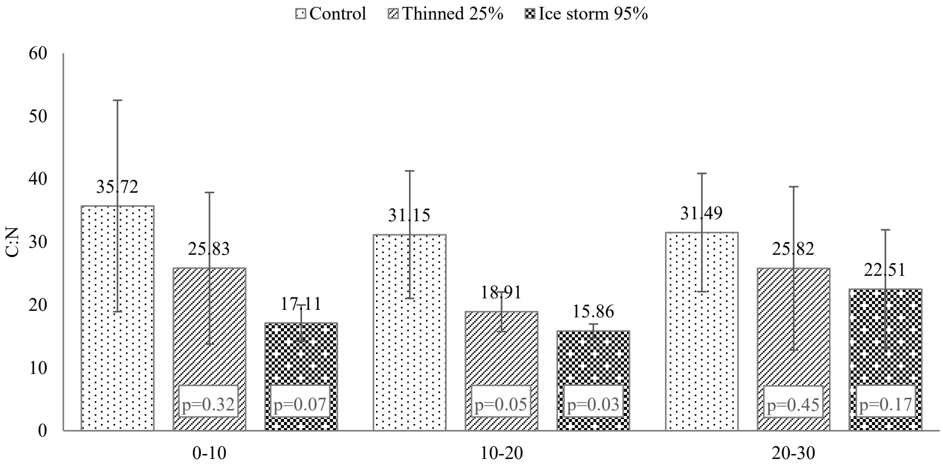

Figure 14. Average C/N ratio (C/N) in the studied soil layers ± standard deviation and p-value between the control and the studied plots

The calculated average C/N ratio for the studied soil layers varies between 31 and 35 for the control plot, from 18 to 26 for thinned plot, and between 15-23 for the damaged from ice storm plot (Figure 14). The p-values, obtained from the t-test, indicate significant difference in the 10-20 cm soil layer between the control and the damaged plot.

The average total nitrogen stocks calculated for the studied layers do not fluctuate in wide ranges between the plots. In the control Nstocks are 0.86 t/ha for the 20-30 cm and 10-20 cm layers, and it goes to 1.06 t/ha in the top soil layer (Figure 15). For the thinned plot the calculated mean Nstocks are 1.00 t/ha for the 0-10 cm, 1.16 t/ha for 10-20 cm, and 1.20 t/ha for 20-30 cm layer. The damaged from ice storm plot has the highest total nitrogen stocks – respectively 1.46 t/ha (0-10 cm), 1.11 t/ha (10-20 cm), and 1.34 t/ha (20-30 cm). There is no statistical difference, considering the obtained p-values.

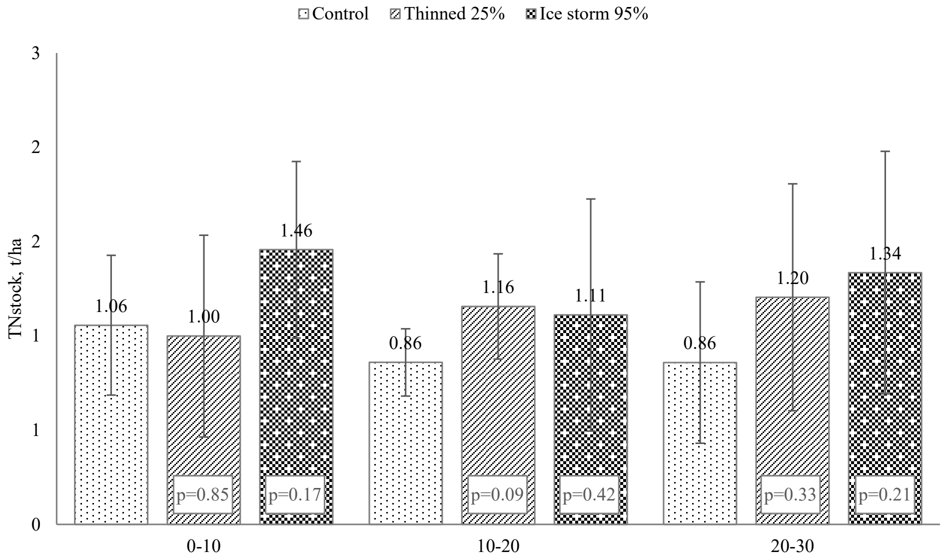

Figure 15. Average total nitrogen stock (N, t/ha) in the studied soil layers ± standard deviation and p-value between the control and the studied plots

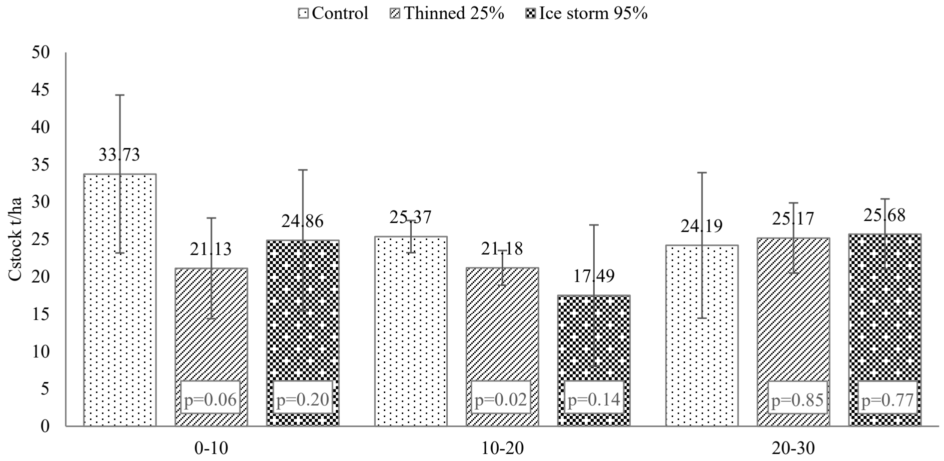

Figure 16. Average organic carbon stock (C, t/ha) in the studied soil layers ± standard deviation and p-value between the control and the studied plots

The average soil carbon stock (Cstock) in the top soil layer varies between the tree studied plots from 21.13 t/ha in the thinned plot, through 24.86 t/ha in the managed after ice storm, to 33.73 t/ha in the control plot. For the second studied layer 10-20 cm the variation is from 17.49 t/ha in the damaged from ice storm plot, through 21.18 t/ha in thinned plot, to 25.37 t/ha in the control plot (Fig. 16).

Discussion

Forest floor

Mountain ecosystems are highly sensitive and vulnerable to environmental changes and different impacts (Glushkova et al., 2020). The forest floor was considered to be easily influenced by thinning intensity (Vesterdal,1995). A thinning operation is followed by a change in forest floor microclimate towards reduced evapotranspiration and increased solar and. thermal radiation (Bala et al., 2006). These changes provide more favorable moisture and temperature regimes for decomposing microorganisms and increase the mineralization rate (Vesterdal,1995). Furthermore, reduced competition between the remaining trees might increase the amount of available nutrients per tree without actually increasing the nutrient capital of the site and result in a more nutrient-rich and easily decomposable litter (Yingrui et al., 2023). However, after a few years canopy closure and root development will suspend the effects of thinning (Vesterdal,1995). Consequently, the effect of thinning in a long-term perspective must depend on both frequency and intensity of the individual thinning operations. The thinning operations which have been repeatedly performed in the investigated plots may thus be expected to have created different conditions for mineralization over many years. A tendency towards more favorable conditions for mineralization, i.e. higher pH and lower C/N was found in the thinned plot. This indicates that the accumulation in the thinned plot might be more influenced by the microclimate than by a possible nutritional effect of thinning, since pH and C/N ratio were only little affected. At the same time, we can assume that in the plot damaged by the natural disturbances, followed by reforestation with spruce coppice and natural regrowth of local species, the microclimate conditions don't differ significant anymore – 10 years after the ice storm, and the canopy is closed. There is no significant difference in the quantities of the forest floor on the studied plots, but the water content is statistically higher in the managed plots, comparing to the control. This may be due to the increased ambience of broadleaved local species, for the damaged from ice storm plot as reported in other studies (Shinohara and Otsuki, 2015). Overall, the carbon stock in the forest floor doesn't differ between the studied plots. The calculation of the carbon stock of the forest floor depends on its quantities which doesn't differ significant in the studied plots. Thus, we may conclude that the observed difference in the carbon content is not significant for the ecosystem carbon stocks, it is more related to the availability of the nutrients, and the mineralization rates.

Soil

Research on the impact of thinning over the soil bulk density, in spruce forests, has shown mixed results. In some studies, it was found that thinning increased soil bulk density (He et al., 2018), while other – that thinning influenced tree characteristics and growth, but did not specifically address changes in soil bulk density (Pfister et al., 2007; Misson et al., 2005). Silvicultural thinning in spruce forests can have significant impacts on soil properties, including bulk density. However, the effects of thinning on soil bulk density may vary depending on the specific thinning method and intensity. In the current study there is a trend of compaction of the soil in depth, which is typical for the studied *Cambisols* (Koinov et al., 1998). Between the control and the managed plots there is no significant diference in the bulk density which can let us to assume that the soil porosity has not been affected too, as a result of the anthropogenic intervention in the managed areas (Shaheb et al, 2021).

The observed increase in the water content of the forest floor can lead to a reduction in soil moisture, particularly during the growing season (Kellomäki et al., 1996), which is observed in the present study for the damaged from ice storm plot. In moisture soil, the use of heavy machinery in forest operations can reduce soil porosity (D'Acqui et al., 2020). The forestry activities in the studied plots were not conducted with heavy machinery which preserved this soil indicator. In spruce crops, given the specificity of the morphology of the root system of this species, a tendency of gradual reduction of fine roots in depth is noticed (Dimitrova et al., 2015), which also leads to a decrease in soil moisture (Messenger, 1980). Considering the management in the thinned and after-ice storm plots which lead to a decrease in the density of the trees and their roots, it is acceptable to conclude that the management has its effect for the observed soil moisture reduction.

The content of coarse fractions in forests is a critical factor in estimating soil pool of carbon (Poeplau et al., 2016). Therefore, understanding the distribution and content of coarse fractions in spruce forests is essential for accurate estimation of soil nutrient pools and for effective forest management. In some studies, an inverse relationship between skeletal content and bulk density has been found (Guidi et al., 2014), which is also confirmed by the data obtained in this study.

Spruce contributes to increasing soil acidity (Kostić et al. 2012). Stand age has also been proven to affect soil pH in spruce plantations, with lower pH values in the soil of older stands (from 37 to 150 yrs) in comparison to younger spruce plantations – under 20 yrs (Smal and Olszewska, 2008). The results of this study suggest otherwise. There is no significant difference in the pH between the studied plots, which could be due to the obstacles connected with the land-use history of the plots, soil type, maturity rock etc., and additional studies are needed.

Thinning can have complex and varied effects on soil carbon content in spruce forests. Some studies observed decrease in soil respiration rates immediately after thinning, followed by a gradual increase of soil carbon content (Pang et al., 2016). In other it was found that with increasing thinning intensity soil carbon content decreases (He et al., 2018). It was also noted a site-specific response, with a slight decrease in forest floor carbon but an increase in mineral soil carbon under thinning treatments (Kim et al., 2019). When felling is carried out, in which the preservation of the good condition of the plantation and the habitat is observed, a weak or no effect on the content of org. C in the soil and the reduction in the amount of fresh fall applied is compensated by the fallow left (Lal, 2005). These findings suggest that the impact of thinning on soil carbon content in spruce forests is influenced by a range of factors, including forest type, environmental conditions, and the specific management practices used. This study contributes to the findings that the thinning practices conducted low intensity, and with attention for maintaining the habitat, leads to no significant changes in the soil carbon content. For the damaged from ice storm plot we could note that although the conducted heavy thinning – over 95 %, reduced more plant photosynthetic biomass, decomposition of dead roots, litterfall, and woody debris can only offset the decrease in soil organic carbon, within a certain time scale after thinning and thus led to no significant changes in soil carbon content in heavy thinned plot.

There is a positive correlation between the organic carbon content and the total nitrogen content in the soil (Xue and An, 2018). In the present study while the organic carbon content does not differ between the studied plots, the total nitrogen is significantly higher in the managed sites. Low intensity thinning in spruce forests can

lead to an increase in soil total nitrogen (Wang et al., 2010). On the long-term, the removal of tree biomass in form of stems, branches, and leaves and the associated decreased litter fall and discontinuation of a steady input of N-containing biomass can reduce total N contents in the soil (Olsson et al., 1996). Depending on the further development of understory vegetation, this loss of N input into the soil can partly be diminished by the reduced N plant uptake after high intensity thinning (Siebers and Kruse, 2019), which can also affect the C/N ratio. The C/N ratio is barely affected in the damaged from ice storm plot, in the 10-20 cm soil layer, in positive direction. The lack of change in this parameter is actually a good result, because it indicates that the decomposition rate and the quality of the compost are good. The optimal carbon-nitrogen ratio for composting is between 25-30 to 12.

Management practices may affect C dynamics (Yang et al. 2011) and alter C storage in forest ecosystems (Powers et al. 2011). Thinning improves the growth conditions of remaining trees (Balboa-Murias et al. 2006), affects stand conditions and soil environmental factors such as soil moisture and temperature (Kim et al. 2009), and thus influences forest C storage, dynamics and cycling (Nilsen and Strand 2008). Overall, the studied soils in the control, thinned with 25 % intensity, and cleared after ice storm with over 95 % of the biomass, plots did not occur with significant differences in the studied properties, which could lead to decrease in the carbon stocks.

Conclusions

Forest floor characteristics undergo changes, which we observed ten years after thinning activities and natural disturbances, can be related more to the availability of the nutrients, and the mineralization rates, than to its carbon stocks.

Soil pH depends on many factors, and the present study results contribute to the idea that the vegetation type is not the leading factor for soil acidity. The rich variety of soil types, and other conditions, in Bulgaria provoke the conclusion that more studies, connected with the changes in this parameter, are needed.

The results of the experiment show that the forest management carried out in compliance with the requirements for the protection of the habitat and the functionality of the ecosystem in the studied sites did not lead to negative changes in the studied soil properties.

Taking soil carbon accumulation into consideration we can conclude, that light thinning (thinning intensity < 33%) is recommended for silvicultural practice, but when needed the clear cuttings and afterall activities can be conducted with preservation of the soil function to accumulate carbon and nitrogen. We can also suggest that having more long-term field experiments to study soil carbon stocks and dynamics under different thinning intensities is need to fulfill the knowledge and understanding the processes of accumulating organic carbon and total nitrogen in the soil.

Acknowledgemens

This work has been supported by the Ministry of Education and Science and the National Science Fund approved after participation in competition for financial support for projects of young scientists and postdoctoral students (КП-06-М56/1).

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