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Influence of the logging season on the condition of topsoil layers

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Abstract: Proper management at the stage of forest utilization should take into account the need to protect soils, and one of its forms is timber harvesting performed in periods when soil disturbance is least likely. Such conditions occur, inter alia, when the soil is frozen and protected by a layer of snow. The aim of this study was to determine whether topsoil disturbances after timber harvesting in summer and winter seasons differ in terms of quality and dimensions. The study was carried out in southern Poland, in an oak stand which underwent late thinning. Tree felling and delimbing was performed with the use of chainsaws. The harvested timber was extracted with the use of farm tractors, by means of skidding in the case of long logs and by means of forwarding in the case of rollers. The logging tasks were carried out in two periods: in summer and winter, the latter under conditions of temperatures below zero and the presence of the snow cover. Two experimental plots were established in the stand, one located in its fragment used in summer and the other in winter. The plots had the shape of a square with a side of 100 meters. Their area was divided into 100 one-are measurement fields, which were squares with a side of 10 m. After the completion of logging tasks, the dimensions of the resulting soil disturbances were determined at each field. Timber harvesting in winter had a positive impact on the protection of topsoil layers. The share of disturbed soil was lower (0.6%) on the plot where felling had been performed in winter as compared to summer felling (2.6%). The area, volume and depth of soil disturbances were statistically significantly higher after timber harvesting in the summer period. Timber harvesting in the winter period resulted in the soil condition undisturbed in 70% whereas in the summer season it was about 40%.

Key words: Timber harvesting, soil damage, summer, winter

INTRODUCTION

Timber harvesting is inextricably related to the adverse effects on forest soil. During the implementation of timber harvesting treatments, soil disturbances are formed as a result of the movement of vehicles as well as the movement of timber itself (Błażejczak et al. 2015). This may cause changes in the physical properties of the soil: porosity, infiltration capacity, bulk density and shear strength (Nawaz et al. 2013). They influence the chemical and biophysical processes in the soil and thus the long-term productivity of the stands (Munteanu and Apăfăian 2015). Proper management at the stage of forest utilization should therefore take into account the need for soil protection, which can be implemented on two levels: active and passive (Kulak 2017). The former level concerns the proper design and use of skid trails and machinery applied in the timber harvesting process. The main advantage of the use of skid trails consists in limiting only to their surface the adverse impact of the movement of machines applied in the adopted technology (Sadowski et al. 2016). Moreover, the proper stand accessibility via skid trail networks increases the efficiency of the performed operations and sometimes determines the possibility of their implementation (Kulak et al. 2016). The trend in the construction of timber harvesting machines is mainly aimed at reduction of their unit ground pressure. This is possible, for example, through the use of wide tyres, removable tracks put on wheels (Lukáč and Koreň 2004), or drive systems with a larger number of wheels or with tracks (Sakai et al. 2008). The latter, passive level consists in carrying out harvesting operations in the period when significant disturbance of the soil layer is least likely. For example, moving felling operations to dry periods may significantly reduce the depth of ruts formed in the forest stand (Cambi et al. 2015). Timber harvesting in winter, with frozen soil and the snow cover, i.e. the so-called seasonality of forest work, has been used traditionally (Bluszkowska and Nurek 2010) also to reduce anthropopressure on the forest environment. However, there are reports that timber harvesting in the winter season will not always and not under all conditions lead to the reduction of damage caused by timber harvesting (Šušnjar et al. 2006).

The aim of the study was to evaluate whether topsoil disturbances caused by timber harvesting in the summer and winter seasons differ in quality and dimensions.

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MATERIALS AND METHODS

The study was carried out in the Pińczów Forest District, located in southern Poland, in the Regional Directorate of State Forests in Radom, in a forest compartment where oak was the dominant species (Table 1). The stand underwent tending cuts done as part of the framework of late thinning.

Table 1. Basic characteristics of the stand in which the study was carried out

Feature	Value
Coordinates	50°28'3"N20°37'4"E
age (years)	84
area (ha)	6.17
species composition	80% oak, 20% pine
treatment	late thinning
stand density	discontinuous
stand volume (m3/ha)	340
Forest site type	fresh broadleaved forest
Site index	II/I
mean breast height diameter (cm)	40/36
mean height (m)	27
Soil	gleyic luvisol

Timber harvesting was carried out in the manual-machine technology. Tree felling and delimbing was performed with the use of chainsaws, producing long logs with the length of up to 11 m and rollers with the length of 1.25 m. The logs were extracted from the stand by means of skidding with the Valmet 6400 tractor (Table 2) equipped with the Uniforest50EH cable winch, while the rollers were forwarded with the MTZ tractor equipped with a self-made trailer, and were loaded manually. For the purpose of loading, both tractors travelled up to the timber to be transported..

The logging tasks were carried out in two stages: in summer (September), with low rainfall and temperatures of 8-18oC and in winter (December), with temperatures from -2 to -15^{o}C and the snow cover of about 15 cm. In the stand, two experimental plots were established in representative places in such a way that one, marked with symbol "S", was located in the stand fragment used in the summer while the other, marked with symbol "W", in the winter. The plots had the shape of a square of 100 x 100 meters. Their area was divided into 100 one-are measurement fields in the shape of squares with sides of 10 m, and their nodal points were marked with wooden stakes. Each experimental plot was located so that one of its sides was adjacent to the skid trail. Immediately after the completion of the logging tasks, in the case of the stand fragment where logging took place in winter, the dimensions of the resulting soil disturbances were determined on each plot immediately after the disappearance of the snow cover. Using a steel tape-measure, measurements exact to 0.5 cm were taken of their length, width as well as depth in relation to the original ground level, determined with a wooden leveling rod. During the measurements, disturbances were simultaneously identified according to Suwała's classification (1999), making a distinction between ruts as traces of machine wheels and furrows created mainly while pulling long logs.

Table 2. Technological means used for skidding

Parameter	Valmet 6400 with a Uniforest50EH cable winch	MTZ 82
Power (kW)	71	60
Weight (kg)	4890	4000
Length (cm)	451	398
Height (cm)	274	280
Tyres size front/rear	14.9 R24/18.4 R34	11.2 R20/15.5 R38
Pulling force (kN)	50	-
Rope – length/ diameter (m/mm)	70/11	-

Based on the observations of the soil surface around each of the 242 nodal points, soil damage was assessed based on Dyrness' classification (1965) with modifications by Giefing (Giefing 1999, Giefing et al. 2012):

1) undisturbed soil – forest litter retained, no traces of compaction, disturbance class R = 0,

2) slightly damaged soil, this class consists of three subclasses:

a) forest litter removed, mineral soil exposed but undisturbed, disturbance class R =1,

b) mineral soil mixed with forest litter, disturbance class R = 2,

c) mineral soil covers forest litter and logging slash with a layer of up to 5 cm, disturbance class R = 3,

3) heavily damaged soil, soil surface layer removed, deeper layers exposed, soil surface sparsely covered with forest litter or logging slash, disturbance class R = 4,

4) compacted soil, visible traces of compaction by a

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logging vehicle or a load, disturbance class R = 5.

Trees growing on the experimental plots were inventoried and measured twice: before and after the treatment, taking into account only trees with a diameter at breast height exceeding 7 cm. Next, the intensity of the cuts performed was calculated in terms of quantity and volume.

Statistical processing of the collected data was performed with Statistica 9.1 StatSoft PL software using Shapiro-Wilk and U Mann-Whitney tests; and the positional statistics of random variables were also calculated.

RESULTS

On both experimental plots, the thinning was performed with similar intensity, both in terms of the number of trees removed and their volume (Table 3).

Table 3. Characteristics of the completed thinning

	Plot S	Plot W
Stand volume before thinning (m3/ha)	414.7	435.5
Volume of harvested timber (m3/ha)	35.9	39.8
Number of trees before thinning (pcs/ha)	342	310
Number of trees after thinning (pcs/ha)	272	232
Volume of harvested long logs / rollers (m3)	14.0/21.9	18.3/21.5

The share of soil surface affected by the timber harvesting tasks carried out in the summer period (over 2.6%) was significantly higher than in the case of thinning done under winter conditions with the snow cover (about 0.6%) (Figure 1). Regardless of the season in which the thinning was carried out, ruts were the predominant form of disturbance, the area of furrows was almost 20 times smaller than that of ruts. On plot “S”, topsoil disturbances were found on 50% of the measurement fields; whereas on plot “W”, disturbances were noted on 23% of the measurement fields, i.e. the number that was more than 2 times smaller.

The acquisition of data on soil disturbance parameters on 1-are measurement fields enabled statistical analysis of the obtained information. The Shapiro-Wilk test showed that empirical distributions of the volume, area and depth of soil disturbances are not consistent with the normal distribution, therefore non-parametric tests were used for further comparisons. The volume of soil disturbances found on the plot where timber harvesting took place in the summer season (me=0.325 m^3) was more than five

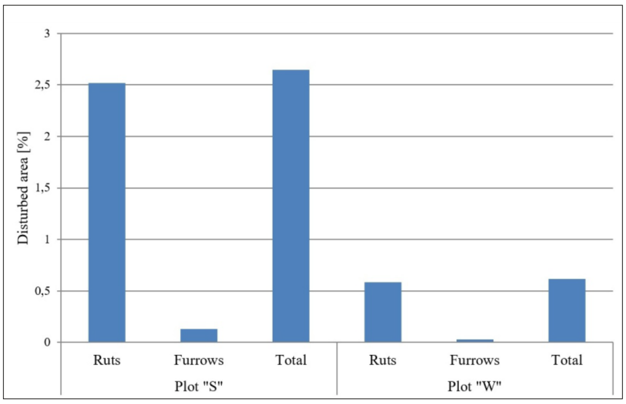

Fig. 1. Area of affected soil

times higher than on the plot with timber harvesting in winter (me=0.061 m3) (Figure 2). The U Mann-Whitney test showed that the differences between the average volume of soil disturbances in the analyzed seasons are statistically significant (Z=5.058, p=0.000).The average

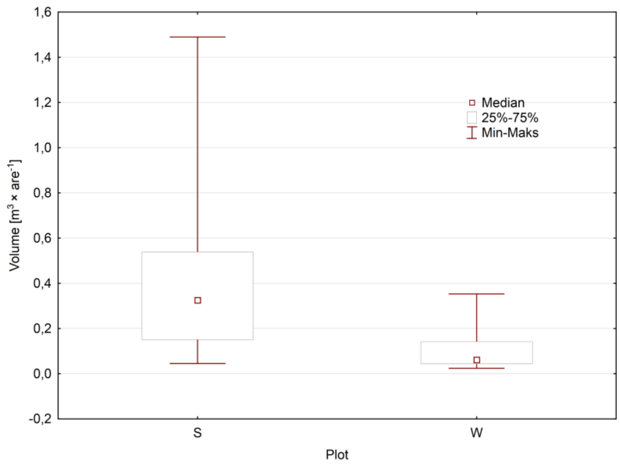

Fig. 2. Volume of affected soil

area of soil disturbances (Figure 3) formed in the course of timber harvesting in the summer season (me=4.26 m^2) was more than twice as large as those formed in the winter season (me=1.76 m^2). Also the minimum and maximum values of disturbance areas formed during the summer logging were about twice as big as those formed during the winter logging. The area of soil disturbances was statistically significantly larger on plot “S” (Z=3.055, p=0.002).

The plots where timber was harvested in summer and winter also differed in terms of depth of soil disturbances (Figure 4). After harvesting in the summer period the depth was almost twice as large (me=7.15 cm) compared to the winter season (me=3.9 cm). The differences in the depth of soil disturbances created in the compared periods are so large that the maximum depths of ruts and furrows created in the winter season are at the level of minimum depths of disturbances remaining after harvesting in the summer period. The average depth also significantly

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differentiated the soil disturbances formed during the summer and winter logging tasks (Z=6.861, p=0.000).

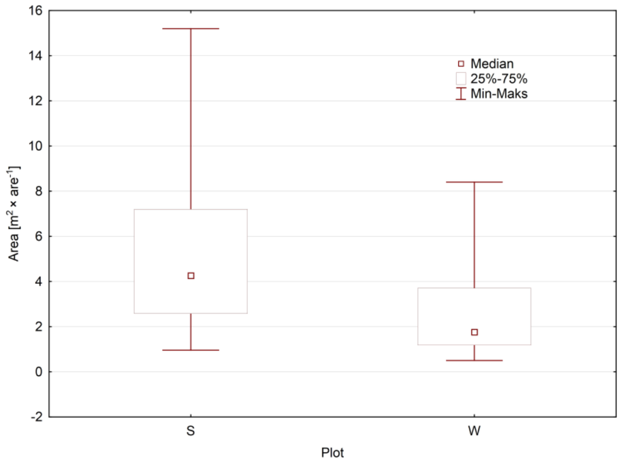

Fig. 3. Area of affected soil

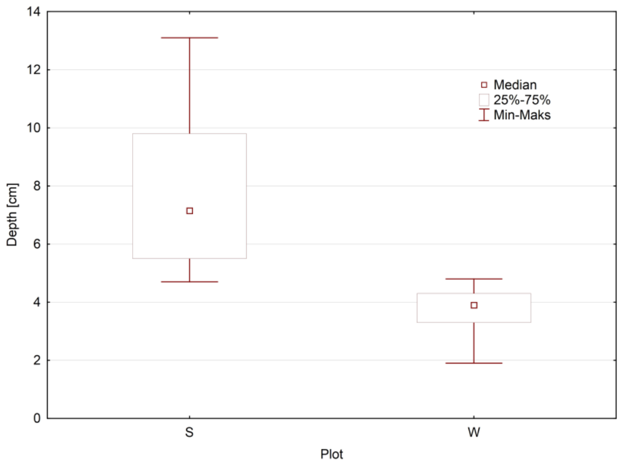

Fig. 4. Depth of soil disturbances

Soil condition assessment done after the harvesting operation, carried out at nodal points and based on Dyrness' scale, made it possible to compare the quality of changes in the topsoil layer observed on each experimental plot (Table 4).

Table 4. Soil disturbances accordibased on Dyrness' classification

Soil – disturbance name and class R	Plot "S"		Plot "W"	
	Number of points	(%)	Number of points	(%)
Undisturbed (R = 0)	46	38.0	85	70.3
Slightly damaged (R = 1)	27	22.3	16	13.2
Slightly damaged (R = 2)	11	9.1	10	5.3
Slightly damaged (R = 3)	10	8.3	6	4.9
Deeply damaged (R = 4)	16	13.2	4	3.3

Plot "W", where logging took place in winter, was characterized by a significantly higher share of points where no soil disturbance was found: they accounted for over 70% of all nodal points. On the other hand, plot "S", where harvesting was done in summer, showed fewer than 40% of nodal points with undisturbed topsoil. Considered jointly, classes R=1, R=2 and R=3, all defined as "slightly damaged soil", constituted fewer than 40% of all nodal points on plot "S"; while on plot "W" their share amounted to about 25%. On both experimental plots, class R=1 was noted as the most numerous one in this group of soil disturbances, whereas classes R=2 and R=3 were observed more than twice as rarely. Deeply damaged soil (R=4) was found at nodal points 4 times more frequently after harvesting in summer than after harvesting in winter. Significant differences were observed in the share of compacted soil (R = 5) on the experimental plots. On plot "W", this form of soil disturbance was not found, while on plot "S" it was observed at nearly 10% of the nodal points.

DISCUSSION

The thinning operations were carried out in a single stand where two experimental plots were established to perform the treatments in the assumed time span. As shown by the tree inventory performed in two stages: before and after thinning, both the number and volume of trees harvested on both experimental plots were similar. This eliminated one of the factors that could have affected the results. Numerous studies demonstrate (Quesnel and Curran 2000, Zenner et al. 2007, Allman et al. 2015) that the intensity of felling significantly affects the extent of timber harvesting damage. This factor has also been used in Poland to model the probability of soil damage during the performance of timber harvesting processes under different conditions using many technologies (Sowa and Kulak 2008).

The quality level of the treatments may also be influenced by the human factor. Sowa (2013) points to a still unresolved problem that economic decisions made by the administration of the State Forests do not always translate into the quality of forest work performed by private service enterprises. As a result, the treatments performed may lead to unsatisfactory forest condition, related, for example, to the excessive level of timber harvesting damage, for which the State Forests National Forest Holding is statutorily responsible. This factor was eliminated in the present study, as the treatments on both plots were performed by the same staff, using the same machines, and therefore the results obtained were most likely influenced by the timber harvesting season.

The dominant form of damage found on the experimental plots were ruts. Despite the skidding of the

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long timber by means of a tractor with a cable winch, the area of furrows was almost 20 times smaller than that of ruts, regardless of the season in which the thinning was carried out. Earlier studies (Kulak et al. 2013) on skidding with the use of a skidder had showed that, in this case, the dominant type of soil disturbance in terms of its area are furrows, the share of which can be up to 3 times greater than that of ruts. Under the analyzed conditions, a tractor equipped with a cable winch travelled up to the extracted timber, and the full reach of the winch was not used. This resulted in an increased share of ruts, with a small share of furrows which would be caused by pulling the timber up to the tractor with the winch. This technology is not optimal, but is often used by cable skidder operators to obtain higher work efficiency.

There is little information in the literature on the extent of soil damage due to timber harvesting under winter conditions. According to Van Rees et al. (2001), timber harvesting during the winter season significantly reduces the formation of ruts by skidding tractors. In the USA, it was proven (Reeves et al. 2012) that frost and the snow cover have the greatest influence on the reduction of the size of the topsoil damage resulting from logging. In Poland, the possibility of limiting the adverse impact of forest utilization processes on the environment through their implementation in the winter season is also indicated (Wojtkowiak et al. 2011, Sadowski et al. 2016, Kulak et al. 2019). However, there are also opinions that carrying out timber harvesting operations in the winter season alone is not sufficient to significantly reduce harvesting damage, as the proper selection of a timber harvesting technology system is equally important (Chmielewski and Porter 2012). The present study has confirmed the effectiveness of soil protection during timber harvesting when carrying out the treatments in the winter period with the snow cover present. Under such conditions, the share of affected soil was about 4.5 times lower than after harvesting in the summer. This trend was also confirmed by analyses of soil disturbance dimensions, performed on the experimental plots. The disturbances caused in the winter period had statistically significantly lower depth, area and volume than those created during harvesting in the summer season.

The share of soil affected after harvesting in the summer season at the level of about 2.6% is low, but does not differ significantly from the data presented in the literature. A universal tractor equipped with a winch, applied in late thinning for the purpose of skidding the timber, may damage from 3.1% (Porter 1997) to 4% of the felling area (Sowa and Kulak 2007a). The soil disturbances observed in this study as a result of winter harvesting, and amounting to 0.5% of the felling area, are very small as for the technology of skidding with universal tractors. A higher level of damage was observed for horse skidding, which is considered to cause extremely low environmental damage. For example, in the late thinning of pine stands where horse skidding was used, the share of disturbed soil ranged from 2.2% (Sowa and Kulak 2007b) to 2.6% (Suwała 2004).

The qualitative analysis of the soil condition at the nodal points showed that timber harvesting done in winter has the strongest impact on the number of points without soil disturbance (R=0), which accounted for more than 70% of all points, while after harvesting in summer their share was below 40%. In the case of winter harvesting, the number of points with slightly damaged soil (R=1,2,3) and deeply damaged soil (R=4) was reduced by almost a half, while the points with compacted soil (R=5) were eliminated in 100%. As shown by another study (Kulak 2014), in a mature beech stand where the harvesting technology (chainsaws and long log skidding with a farm tractor) used was similar to the one analyzed in the present study, the share of intact soil (R=0) was found to be similar to the share of about 40% obtained on plot “S”, while the share of compacted soil (R=5) was noted as slightly higher (17-25%) than in the present research.

SUMMING UP

In the analyzed stand, timber extraction was performed with the use of farm tractors adapted to timber transport by means of skidding and forwarding. This resulted in the formation of topsoil layer disturbances in the form of both ruts and furrows. Timber harvesting during the winter season, at temperatures below zero and in the presence of the snow cover, allowed for significant reduction of harvesting damage as compared to harvesting during the summer. The total share of the affected soil cover was thus reduced from 2.6 to 0.6%, ruts from 2.5 to 0.6% and furrows from 0.1 to 0.03%. The analysis of soil disturbances on the measurement fields showed that winter harvesting allowed for a statistically significant decrease in the following respects: the mean volume of damage from 0.033m^3/are to 0.06 m^3/are, the mean area of damage: from 4.3 m^2/are to 1.8 m2/are, and the mean depth of damage from 7.2 cm to 3.9 cm. The qualitative assessment of the soil condition carried out using Dyrness’ scale also showed that winter harvesting has a less adverse effect on this condition: about 70% of the nodal points were found to have undisturbed soil. On the other hand, harvesting in the summer season resulted in fewer than 40% of such points. As compared to summer harvesting, in winter the occurrence of slight damage (R=1, 2 and 3) was

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reduced from nearly 40% to less than 25%, and deep damage (R=4) from more than 13% to just over 3%. Soil compaction (R=5), which after the treatments performed in the summer season was observed at nearly 10% of the points, was eliminated in winter.

Tested in this study, the method of soil protection against disturbances caused by late thinning, and consisting in treatment performance during the winter period, has proven to be very effective. It can be particularly recommended in areas that are environmentally valuable and sensitive to damage due to timber harvesting.

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