**SYLWAN** 167 (3): 136-144, March 2023
https://doi.org/10.26202/sylwan.2023022
Journal homepage: https://sylwan-journal.pl

**ORIGINAL PAPER**

# Effectiveness of branch mats in soil protection on skidding trails during timber forwarding

Dariusz Kulak✉, Krzysztof Leszczyński, Arkadiusz Stańczykiewicz, Grzegorz Szewczyk

University of Agriculture in Krakow, Faculty of Forestry, Department of Forest Utilization, Engineering and Forest Technique, al. 29 Listopada 46, 31-425 Kraków

## ABSTRACT

Mechanization of logging work, in addition to its undoubted advantages, such as increased safety and productivity, lower unit costs of timber harvesting, is also associated with negative consequences, which include adverse effects of noise and exhaust fumes, local oil pollution, damage to trees and soil. Various solutions are being used to protect forest soils, such as 1. using machinery that exerts low pressures on the ground, 2. limiting work, especially in the most sensitive habitats to periods when the soil is dry or protected by snow cover. It is also important to conduct passes of machinery used for logging and wood extracting along properly planned skid trails. Such management is now commonplace in most Polish forests. The use of trails provides an opportunity for effective soil protection. Covering the surface of trails with a layer of branches left over after limbing trees can further reduce soil compaction. This study aimed to determine the effect of branch mats in the form of logging residues on the changes in soil compaction along skid trails during forwarding using a forest trailer attached to a farm tractor. The fieldwork for this study was carried out on two habitats – a fresh mixed coniferous forest and a fresh mixed deciduous forest. The forwarding set made five passes along the newly established skid trail. A part of the trail was protected by a layer of branches with a thickness of about 5 cm and an average weight of 5.0 $kg \cdot m^{-2}$. After successive passes of the forwarding set, soil compaction in ruts was measured using an electronic penetrometer. Control measurements were also made. Cone index values were used to measure soil compaction, which was found to be linearly increased in both habitats with successive passes. Results showed that compaction of the protected ground was statistically significantly lower than that of the unprotected ground. On both habitats combined, after the fifth pass, the compaction of the protected ground increased by about 1.4-1.6 times, whereas that of the unprotected ground increased by about 1.7-1.8 times. A multiple-regression model was constructed in which soil compaction in ruts depended on the habitat type of the forest, the number of passes of the forwarding set, and the presence of the branch layer. The presence of branch mats had the highest effect on changes in soil compaction in ruts. The findings of these analyses recommend the use of logging residue mats during skidding to prevent excessive increases in soil compaction.

## KEY WORDS

cone index (CI), farm tractor with forest trailer, soil compaction, soil disturbance

✉e-mail: dariusz.kulak@urk.edu.pl

Received: 24 April 2023; Revised: 26 June 2023; Accepted: 27 June 2023; Available online: 24 July 2023

## Introduction

Machinery used in the skidding process is often characterized by high weight and unit pressures (Więsik, 1996; Kormanek and Dvořák, 2021). Thus, it can adversely affect forest soils, causing an increase in their density, formation of ruts, and soil displacement, among others (Giefing *et al.*, 2012; Poltorak *et al.*, 2018). One of the ways to protect the soil is to move the machinery only along skid trails that are lined with a layer of logging residues (Sadowski *et al.*, 2016). In the cut-to-length logging system, which has become increasingly popular in Poland (Mederski *et al.*, 2016), during timber processing, a residue layer consisting of branches, tops, and leaves is used in front of the harvester (Labelle *et al.*, 2015). Thus, two zones are formed: a trail reinforced by the layer of branches and wood storage around the trail (Labelle and Jaeger, 2019). This way, the adverse effects of the machinery used in the logging process on the soil are reduced, and the trail is further reinforced, which is especially important in areas characterized by soils with low bearing capacity (Poršinsky *et al.*, 2011). However, sorting composite wood in the storage area makes the extracting process more efficient. It is presumed that forwarders are more important in soil compaction in mechanized harvesting as they have a higher weight than harvesters and their technology of work requires multiple passes along the skidding trail. Hence, most of the research on protecting the soil on skidding trails using branch mats focuses on forwarders (Partington and Ryans, 2010). However, this method of soil protection can also be used for other skidding means, such as forest trailers attached to farm tractors, which is popular in Poland and many other countries of eastern and southern Europe (Spinelli *et al.*, 2013; Moskalik *et al.*, 2017; Kulak *et al.*, 2023). The magnitude of soil deformation during forwarding is dependent on soil type and moisture content, as well as technological factors such as unit pressures exerted by the extracting machine, the number of passes, and the presence and quality of protective branch mats (Han *et al.*, 2006; Labelle and Jaeger, 2012). Hence, numerous studies need to be conducted on the effectiveness of protecting forest soils using branch mats under varying habitats and conditions.

This study aimed to determine the effect of branch mats on changes in soil compaction on skid trails during forwarding of timber using a forest trailer attached to a farm tractor. The scope of work was limited to two stands growing on soil type Albic Brunic Arenosols, differing in fertility.

## Methods

This study was carried out in the territory of the Staszów Forest District, in two stands growing on the same soil type – Albic Brunic Arenosols, developed on sands and loamy sands, but with different habitat types of the forest. Soils dominated by sand accompanied the poorer habitats – fresh mixed coniferous forest (BMśw), and soils with a higher share of fine fractions accompanied the more fertile habitats – fresh mixed deciduous forest (LMśw). Timber forwarding was carried out in these sites using a John Deere 3300 farm tractor with a weight of 3425 kg, which was equipped with a Palms 8S forest trailer with a weight of 1920 kg. Loads were pine logs with a volume of 3.4-4.2 $m^3$ and a weight of 2516-3108 kg. The fieldwork was carried out in autumn, during a period without precipitation, with an average temperature of about 10°C. Soil compaction was measured using an Eijkelkamp 06.15.SA Penetrologger electronic penetrometer (Eijkelkamp Agrisearch Equipment, Giesbeek, Netherlands) equipped with a 60° cone with an area of 1 $cm^2$. The cone index (CI) (ASAE EP542) can be determined using this device, which is the average soil compaction from the depths of 0.01, 0.15, 0.30, and 0.45 m. CI values were determined while evaluating soil compaction using a penetrometer when the cone reaches a depth of 0.45 m. A new skid trail was established in each habitat, along which a forwarding set with a load was driven. On each trail, 5 test plots were established one after the other, every 10 meters. Along plot No. 1, the forwarding set drove once. Along plot No. 2 the forwarding set drove twice, and so on, and along plot No. 5 it drove five times. Each test plot was divided into two sections 10 m long, with a 2 m gap between them. The first section was uncovered, and a layer of branches about 5 cm thick and with an average weight of 5.0 kg·m$^{-2}$ was lined on the second section. Based on the methodology described in the literature (Pszenny, 2020), on each section, after the planned number of passes, along the axis of the ruts, compactness measurements were taken with a penetrometer every 1 meter (10 measurements in the left rut and 10 in the right rut). In addition, 50 comparative measurements were taken off-trail, along the test plots, at a distance of 2 meters from the ruts.

A total of 500 penetrometer punctures were made. Statistical analyses were conducted using the Statistica 12 package (StatSoft Inc., 2014) at a significance level of $\alpha$=0.05. The normality of CI index distributions was evaluated using the Shapiro-Wilk test. The significance of differences in CI indices from sites protected using branch mats and unprotected sites was analyzed using the Mann-Whitney *U* test. Using multiple regression analysis, the parameters of the equation showing the relationship between the CI indices, and the number of forwarding set passes, habitat type and presence of branch mats were estimated. The significance of individual independent variables was assessed using Student's *t*-test, and the entire models were assessed using Fisher's test (Stanisz, 2007).

## Results

CI values were not normally distributed. This was confirmed by the Shapiro-Wilk test performed for indices characterizing the soil compaction of the mixed coniferous forest habitat (W=0.969, $p$=0.006) and for those of control measurements (W=0.903, $p$=0.000). Similar results were obtained for the mixed deciduous forest habitat, with W=0.963, $p$=0.002; and W=0.906, $p$=0.000. Therefore, for further analysis, nonparametric statistics were used.

CI values on both analyzed habitats after successive passes of the forwarding set (Figs 1 and 2) increased almost linearly. Control measurements, taken off trail, showed that the soil on

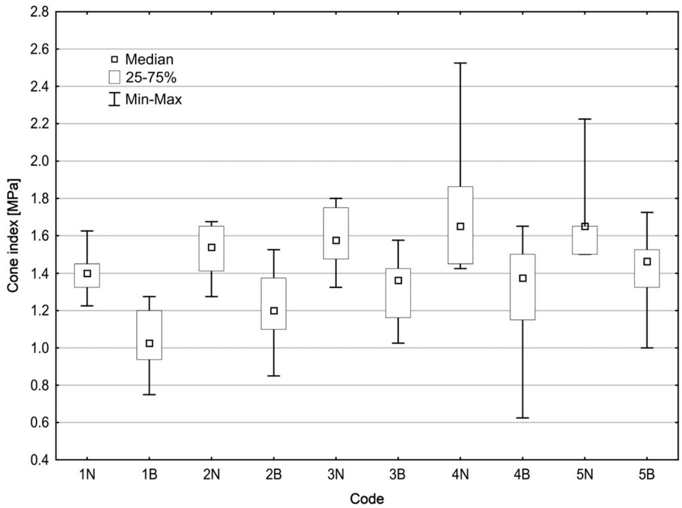


**Fig. 1.**

Changes in soil compaction after successive passes on the fresh mixed coniferous forest (BMśw) habitat
numbers 1 to 5 – numbers of successive passes, N – unprotected soil, B – soil protected with a layer of branches

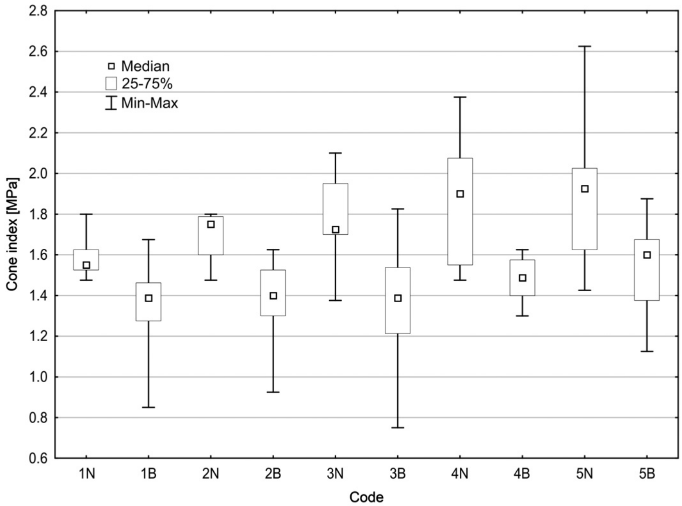


**Fig. 2.**
Changes in soil compaction after successive passes on the fresh mixed deciduous forest (LMśw) habitat
numbers 1 to 5 – numbers of successive passes, N – unprotected soil, B – soil protected with a layer of branches

the BMśw habitat was characterized by slightly lower CI values (me=0.925 MPa) than the soil on the LMśw habitat (me=1.150 MPa). The first pass of the forwarding set increased ground compaction in the mixed coniferous forest habitat to 1.02-1.40, depending on whether the trail was protected using a branch mat or not. After the final fifth pass, soil compaction increased to 1.46-1.65 MPa, respectively. In the mixed deciduous forest habitat, the change in the increase in soil density was higher, from 1.39 to 1.55 MPa after the first pass to 1.63 MPa after the fifth pass on a trail protected by a layer of branches and up to 1.93 MPa for an unprotected trail.

After each pass, the unprotected ground showed higher compaction than the protected ground. Mann-Whitney *U* tests showed that in both habitats and after each tractor pass, CI indices were statistically significantly higher for the unprotected ground (Table 1).

Changes in soil compaction in control measurements after successive passes were also summarized (Table 1). Branch mats showed their ability to protect the soil of the skidding trail from compaction due to forwarding set passes. In both habitats combined, after the fifth pass, the compaction of the protected soil increased by about 1.4-1.6 times, whereas that of the unprotected soil increased by about 1.7-1.8 times. The first pass resulted in significant soil compaction, during which the unprotected soil compacted by about 35-51% depending on the habitat, whereas the protected soil compacted by 11-21%. After the first pass of the forwarding set, the rate of increase in soil compaction was found to be relatively constant.

A multiple-regression model was constructed, in which soil compaction in ruts depended on the habitat type of the forest, the number of passes of the forwarding set, and the presence of a branch layer. The resulting model can be expressed as follows:

$$CI = 1.53 - 0.194 \cdot H + 0.101 \cdot N - 0.437 \cdot B \pm 0.293 \text{ [MPa]} \quad [1]$$

where:

$CI$ – the cone index;
$H$ – the variable indicating the type of habitat: 1 – BMśw and 0 – LMśw;
$N$ – the number of passes of the forwarding set (0-5);
$B$ – the variable indicating ground cover: 1 – branch overlay and 0 – no ground cover.

**Table 1.**

Changes in soil compaction after successive passes of the forwarding set and the significance of differences in CI indices between the soil protected using branch mats and the unprotected soil (Mann-Whitney U test)

| Pass | Fresh mixed coniferous forest (BMśw) | | | Fresh mixed deciduous forest (LMśw) | | |
|---|---|---|---|---|---|---|
| | change in compaction compared with the control measurement [%] | | significance of CI differences | change in compaction compared with the control measurement [%] | | significance of CI differences |
| | unprotected | branch mat | | unprotected | branch mat | |
| 1 | 151.4 | 110.8 | $U$=4.0; $p$=0.002 | 134.8 | 120.7 | $U$=6.5; $p$=0.003 |
| 2 | 166.2 | 129.7 | $U$=14.5; $p$=0.002 | 152.2 | 121.7 | $U$=7.0; $p$=0.010 |
| 3 | 170.3 | 147.4 | $U$=16.5; $p$=0.023 | 150.0 | 120.7 | $U$=23.0; $p$=0.006 |
| 4 | 178.4 | 148.6 | $U$=24.0; $p$=0.011 | 165.2 | 129.4 | $U$=17.0; $p$=0.006 |
| 5 | 179.5 | 158.1 | $U$=18.0; $p$=0.007 | 167.4 | 139.1 | $U$=21.5; $p$=0.026 |

For the obtained model, $R$=0.78, and the model was statistically significant ($F$=251.53; $p$=0.00), explaining 60% of the variation in the values of CIs. The magnitudes of the standardized regression coefficients indicated that the number of forwarding set passes had the highest effect on soil compaction in ruts (β=0.62), followed by the presence of branch layers (β=0.41), whereas habitat type (β=0.21) had the lowest but statistically significant effect on soil compaction.

## Discussion

In the present study, the CI index, which provides information about the average compaction of the soil to a depth of 0.45 m, was used to determine the changes in soil compaction due to forwarding. Measurements covered the entire soil layer that is subject to deformation due to the movement of the forwarding set, which can reach a depth of up to several tens of centimeters (Gerasimov and Katarov, 2010; Labelle *et al.*, 2019). Different approaches have been used to analyze the phenomenon of compaction of forest soils, with some researchers focusing on the top 10 cm of the soil, where changes are usually highest (Porter and Porter, 1998). Other researchers analyze the changes in soil compaction at higher depths (Cudzik *et al.*, 2011; Kulak *et al.*, 2015), exceeding 0.5 m (Kormanek *et al.*, 2008), which is reasonable, since – as Pszenny (2020) proved – changes in the compaction of forest soils can be higher at a depth of 20 cm than in the top layer.

Logging residues have been used to protect the surface of skidding trails for a long time (Čižek, 1988; McDonald and Seixas, 1997), but this procedure can be widely used only during harvesting using a harvester. As a part of the applied technology, branch mats can be created without additional requirements. While logging by other means, especially using a chainsaw, the formation of a layer of logging residue is an extremely labor-intensive task (Sadowski *et al.*, 2016). The present study confirmed the protective effect of branch mats. On both habitats, after each of the five passes of the forwarding set, CI values of the soil protected using branch mats were statistically significantly lower than those of the unprotected ground. In the mixed coniferous forest habitat, after five passes, the difference in the compaction between the protected and unprotected soils was 0.2 MPa, whereas in the mixed deciduous forest habitat, it was 0.3 MPa. Hanet *et al.* (2006) reported similar results for a branch mat with a slightly higher density (7.5 $kg \cdot m^{-2}$), who estimated the differences in soil compaction between protected and unprotected soils as a function of depth at 0.19-0.25 MPa.

The resulting changes in soil compaction during forwarding are characteristic of forests. In previous studies, the first pass of the forwarding set causes the highest soil compaction, reaching up to several tens of percent of the maximum compaction achieved after 10 passes (Moskalik and Sadowski, 1998; Han *et al.*, 2006). In the present study, the first pass of the forwarding set resulted in 70-86% of the maximum soil compaction achieved after five passes depending on the variant. The same was also observed after forwarding carried out on a layer of logging residues. Subsequent passes of the forwarding set further increased soil compaction linearly. Numerous studies have reported similar relationships during multiple passes of forwarding sets or forwarders (Solgi *et al.*, 2018; Pszenny, 2020). With numerous skidder passes, changes in soil properties with successive passes are sometimes modeled using a logarithmic function. Such a relationship was observed, for example, in the highly wet soils of Karelia during as many as 100 skidding cycles of the track skidder (Piskunov, 2019).

In the present study, after analyzing the five passes of the forwarding set, soil compaction increased in the unprotected ground, depending on the habitat, by about 170-180% compared with control measurements. Similar values – an increase in soil compaction of 170% – were reported in an earlier study (Kulak *et al.*, 2015) in a pine stand in which forwarding was carried out using an Ursus C-360 farm tractor equipped with a cart with hand loading. Zastocki (2003) observed similar results, who found a 180% increase in ground compaction in a thinned pine stand where skidding was conducted using a farm tractor. Under similar conditions, but using skidding implemented with a farm tractor, Paschalis and Porter (1994) observed a slightly higher increase in soil compaction, exceeding 200%.

Soil compaction can be estimated using multiple regression models, based on variables such as forest habitat type, the number of forwarding set passes, and the presence of a soil protection layer by means of a logging residue layer. Only a few studies have considered the simultaneous influence of multiple factors on the degree of soil compaction. One of them (Solgi *et al.*, 2018) demonstrated that soil compaction is statistically significantly affected by the number of skidder passes, the slope of the terrain, and the thickness of the branch mat. The majority of the studies have discussed the influence of individual factors on changes in soil compaction. For example, Zastocki (2003) analyzed soil compaction after extracting of timber via different means in a fresh coniferous forest and a fresh mixed coniferous forest. Several studies have considered the number of extracting passes as a factor influencing the degree of soil compaction, which, under varying field and technological conditions, have proved significant relationships between changes in soil compaction on skidding trails and the number of passes of different tractors (Labelle and Jaeger, 2012; Solgi *et al.*, 2018; Pszenny, 2020). Studies analyzing the relationship between using branch mats and the size of their layer, and the degree of soil disturbance have usually concluded that using branch mats is effective depending on the density and composition of the branch layer (Labelle *et al.*, 2019; Ring *et al.*, 2021).

## Conclusions

In this study, soil compaction in ruts increased after each of the five passes of the forwarding set consisting of farm tractor with a forest trailer. The protective layer used, logging residues with a thickness of about 5 cm, proved to be sufficient to reduce the degree of soil compaction in both BMśw and LMśw habitats, and after each pass, soil compaction of the trail unprotected by the branch layer was found to be statistically significantly higher. By applying the multiple regression model, soil compaction was measured using independent variables, such as habitat type, the number of passes, and whether a protective mat of logging residues was used. Based on the findings of this study, the use of logging residue mats during extracting can be recommended to protect the soil from excessive soil compaction.

## Authors' contributions

Conceptualization, methodology – D.K.; validation – D.K., A.S., K.L. and G.S.; writing of first manuscript draft – D.K.; review and editing of manuscript versions – A.S. K.L. and G.S.; visualization – K.L. and G.S.

## Conflicts of interest

The authors declare no conflict of interest.

## Funding source

The research was funded by the Ministry of Education and Science of the Republic of Poland.

## References

**ASAE, 1999.** Procedures for using and reporting data obtained with the soil cone penetrometer (ASAE EP542 FEB99), ASAE Standards 2000.

**Čiżek, J., 1988.** Biotechniczne podstawy mechanizacji produkcji leśnej. Warszawa: PWRiL, 307 pp.

**Cudzik, A., Białczyk, W., Czarnecki, J., Brennensthul, M., 2011.** Ocena zmian wybranych właściwości podłoży leśnych przy różnych metodach zrywki drewna. (Assessment of changes of the forest grounds selected properties at different methods of logging). *Inżynieria Rolnicza*, 8 (133): 61-68.

**Gerasimov, Y., Katarov, V., 2010.** Effect of bogie track and slash reinforcement on sinkage and soil compaction in soft terrains. *Croatian Journal of Forest Engineering: Journal for Theory and Application of Forestry Engineering*, 31 (1): 35-45.

**Giefing, D.F., Bembenek, M., Gackowski, M., Grzywiński, W., Karaszewski, Z., Klentak, I., Kosak J., Mederski, P.S., Siewert, S., 2012.** Ocena procesów technologicznych pozyskiwania drewna w trzebieżach późnych drzewostanów sosnowych. Metodologia badan. (Evaluation of thinning operations in older pine stands. Research methods). *Nauka Przyroda Technologie*, 6 (3): #59.

**Han, H.S., Page-Dumroese, D., Han, S.K., Tirocke, J., 2006.** Effects of slash, machine passes, and soil moisture on penetration resistance in a cut-to-length harvesting. *International Journal of Forest Engineering*, 17 (2): 11-24.

**Kormanek, M., Dvořák, J., 2021.** Ground Pressure Changes Caused by MHT 8002HV Crawler Harvester Chassis. *Croatian Journal of Forest Engineering: Journal for Theory and Application of Forestry Engineering*, 42 (2): 201-211. DOI: https://doi.org/10.5552/crojfe.2021.844.

**Kormanek, M., Walczyk, M., Walczyk, J., 2008.** Wpływ obciążenia i liczby przejazdów ciągników zrywkowych na zwięzłości wybranych gleb leśnych. (The effect of load and number of passes of skidding tractors on compaction of forest soils). *Sylwan*, 152 (10): 48-55. DOI: https://doi.org/10.26202/sylwan.2006172.

**Kulak, D., Stańczykiewicz, A., Szewczyk, G., Lubera, A., Strojny, T., 2015.** Czynniki wpływające na zmiany zwięzłości gleb leśnych podczas pozyskiwania surowca drzewnego (Factors affecting the changes in penetration resistance of forest soils during timber harvesting). *Sylwan*, 159 (4): 318-325. DOI: https://doi.org/10.26202/sylwan.2014023.

**Kulak, D., Szewczyk, G., Stańczykiewicz, A. 2023.** Productivity and working time structure of timber forwarding in flatland thinned pine stand with the use of farm tractors. *Croatian Journal of Forest Engineering: Journal for Theory and Application of Forestry Engineering*, 44 (1): 57-67. DOI: https://doi.org/10.5552/crojfe.2023.1656.

**Labelle, E.R., Jaeger, D., 2012.** Quantifying the use of brush mats in reducing forwarder peak loads and surface contact pressures. *Croatian Journal of Forest Engineering: Journal for Theory and Application of Forestry Engineering*, 33 (2): 249-274.

**Labelle, E.R., Jaeger, D., 2019.** Management implications of using brush mats for soil protection on machine operating trails during mechanized cut-to-length forest operations. *Forests*, 10 (1): 19. DOI: https://doi.org/10.3390/f10010019.

**Labelle, E.R., Jaeger, D., Poltorak, B.J., 2015.** Assessing the ability of hardwood and softwood brush mats to distribute applied loads. *Croatian Journal of Forest Engineering: Journal for Theory and Application of Forestry Engineering*, 36 (2): 227-242.

**Labelle, E.R., Poltorak, B.J., Jaeger, D., 2019.** The role of brush mats in mitigating machine-induced soil disturbances: an assessment using absolute and relative soil bulk density and penetration resistance. *Canadian Journal of Forest Research*, 49 (2): 164-178. DOI: https://doi.org/10.1139/cjfr-2018-0324.

**McDonald, T.P., Seixas, F., 1997.** Effect of slash on forwarder soil compaction. *Journal of Forest Engineering*, 8 (2): 15-26.

**Mederski, P.S., Karaszewski, Z., Rosińska, M., Bembenek, M., 2016.** Dynamika zmian liczby harwesterów w Polsce oraz czynniki determinujące ich występowanie. (Dynamics of harvester fleet change in Poland and factors determining machine occurrence). *Sylwan*, 160 (10): 795-804. DOI: https://doi.org/10.26202/sylwan.2016030.

**Moskalik, T., Sadowski, J., 1998.** Einfluss von Holzernte- und Rückemaschinen auf den Waldboden und verbleibenen Bestand. *Forstliche Forschungsberichte*, 174: 74-78.

**Moskalik, T., Borz, S.A., Dvořák, J., Ferencik, M., Glushkov, S., Muiste, P., Lazdiňđ, A., Styranivsky, O., 2017.** Timber harvesting methods in Eastern European countries: A review. *Croatian Journal of Forest Engineering: Journal for Theory and Application of Forestry Engineering*, 38 (2): 231-241.

**Partington, M., Ryans, M., 2010.** Understanding the nominal ground pressure of forestry equipment. *Advantage*, 12 (5): 1-8.

**Paschalis, P., Porter, B., 1994.** Próba oceny uszkodzeń drzew w wyniku prac zrywkowych w sosnowych drzewostanach przedrębnych. (An attempt at assessment of tree injuries as resulted from skidding operations in premature Scots pine stands). *Sylwan*, 138 (9): 17-21.

**Piskunov, M., 2019.** Skidding trail reinforcement with reduced amount of slash. *IOP Conference Series: Earth and Environmental Science*, 226: 012055. DOI: https://doi.org/10.1088/1755-1315/226/1/012055.

**Poltorak, B.J., Labelle, E.R., Jaeger, D., 2018.** Soil displacement during ground-based mechanized forest operations using mixed-wood brush mats. *Soil and Tillage Research*, 179: 96-104. DOI: https://doi.org/10.1016/j.still.2018.02.005.

**Poršinsky, T., Stankić, I., Bosner, A., 2011.** Djelotvorno i okolišno prihvatljivo izvoženje drva forvarderom temeljem analize nominalnoga tlaka na podlogu. (Ecoefficient timber forwarding based on nominal ground pressure analysis). *Croatian Journal of Forest Engineering: Journal for Theory and Application of Forestry Engineering*, 32 (1): 345-355.

**Porter, B., Porter, K., 1998.** Wpływ sposobu pozyskiwania i zrywki na środowisko leśne. *Przegląd Techniki Rolniczej i Leśnej*, 6: 20-22.

**Pszenny, D., 2020.** Wpływ zrywki drewna forwarderem Ponsse Gazelle na zwięzłość gleby. (Impact of Ponsse Gazelle forwarder logging on soil compactness). *Sylwan*, 164 (8): 643-650. DOI: https://doi.org/10.26202/sylwan.2020054.

**Ring, E., Andersson, M., Hansson, L., Jansson, G., Högbom, L., 2021.** Logging mats and logging residue as ground protection during forwarder traffic along till hillslopes. *Croatian Journal of Forest Engineering: Journal for Theory and Application of Forestry Engineering*, 42 (3): 445-462. DOI: https://doi.org/10.5552/crojfe.2021.875.

**Sadowski, J., Moskalik, T., Zastocki, D., 2016.** Ochrona gleby leśnej przy pozyskiwaniu i zrywce drewna (Forest soil protection in timber harvesting and logging). *Studia i Materiały Centrum Edukacji Przyrodniczo-Leśnej*, 46 (1): 173-180.

**Solgi, A., Naghdi, R., Labelle, E.R., Zenner, E.K,. 2018.** The effects of using soil protective mats of varying compositions and amounts on the intensity of soil disturbances caused by machine traffic. *International Journal of Forest Engineering*, 29 (3): 199-207. DOI: https://doi.org/10.1080/14942119.2018.1527174.

**Spinelli, R., Magagnotti, N., Facchinetti, D., 2013.** Logging companies in the European mountain: an example from the Italian Alps. *International Journal of Forest Engineering*, 24: 109-120. DOI: https://doi.org/10.1080/14942119.2013.838376.

**Stanisz, A., 2007.** Przystępny kurs statystyki z zastosowaniem STATISTICA PL na przykładach z medycyny. Tom 2. Modele liniowe i nieliniowe. Kraków: StatSoft Polska, 868 pp.

**StatSoft Inc., 2014.** Statistica (data analysis software system), version 12. Available from: www.statsoft.com.

**Więsik, J., 1996.** Możliwości doboru maszyn przyjaznych dla środowiska leśnego. *Przegląd Techniki Rolniczej i Leśnej*, 1: 13-15.

**Zastocki, D., 2003.** Wpływ stosowanych przez Zakłady Usług Leśnych środków zrywkowych na uszkodzenia gleby i pozostających drzew w sosnowych drzewostanach przedrębnych. (The effect of harvesting systems used by Forest Services Companies on the present and future technical quality of premature pine stands). *Sylwan*, 147 (4): 52-58. DOI: https://doi.org/10.26202/sylwan.2003040.

## STRESZCZENIE

# Skuteczność maty gałęziowej w ochronie gleby leśnej podczas nasiębiernej zrywki drewna

Celem badań było określenie wpływu mat gałęziowych powstałych z pozostałości pozrębowych na zmiany zwięzłości gleby na szlakach operacyjnych podczas nasiębiernej zrywki drewna za pomocą ciągnika rolniczego John Deere 3300 wyposażonego w przyczepę samozaładowczą Palms 8S. Prace terenowe wykonano w Nadleśnictwie Staszów na 2 siedliskach: boru mieszanego świe-

żego i lasu mieszanego świeżego. Zestaw zrywkowy wykonał 5 przejazdów po nowo założonym szlaku zrywkowym. Część szlaku była chroniona warstwą gałęzi o grubości około 5 cm i średniej masie 5,0 kg·m$^{-2}$. Po kolejnych przejazdach zestawu zrywkowego wykonano za pomocą elektronicznego penetrometru po 20 pomiarów zwięzłości gleby w koleinie w miejscu osłoniętym matą gałęziową i 20 pomiarów w koleinie w miejscu niechronionym. Dodatkowo wykonano 50 pomiarów porównawczych, poza szlakiem zrywkowym. Łącznie wykonano 500 wkłuć penetrometrem. Jako miarę zagęszczenia gruntu przyjęto wartości indeksu stożka (CI), będącego uśrednioną zwięzłością gruntu z głębokości 0,01, 0,15, 0,30 i 0,45 m. Wartości wskaźników CI na obu analizowanych siedliskach po kolejnych przejazdach zestawu zrywkowego (ryc. 1-2) rosły w sposób zbliżony do liniowego. Pomiary kontrolne wykonane na gruncie niezagęszczonym wykazały, że gleba na siedlisku BMśw cechuje się nieco niższymi wartościami indeksu stożka (me=0,925 MPa) niż na siedlisku LMśw (me=1,150 MPa). Po ostatnim 5. przejeździe, w zależności od tego, czy szlak pokryty był matą gałęziową, czy też nie, zagęszczenie gruntu wzrosło odpowiednio do poziomu 1,46-1,65 MPa na siedlisku borowym i 1,63-1,93 MPa na lasowym. Zmiany zwięzłości gruntu po kolejnych przejazdach w analizowanych drzewostanach, w zależności od tego, czy gleba chroniona była warstwą gałęzi, zestawiono również w ujęciu procentowym w stosunku do pomiarów kontrolnych (tab. 1). Wyłożone maty gałęziowe wykazały swoją przydatność w ochronie terenu szlaku zrywkowego przed zagęszczeniem wywołanym przejazdami zestawu zrywkowego. Na obu siedliskach łącznie po 5 przejazdach grunt chroniony matami zwiększył swoją zwięzłość około 1,4-1,6 razy, podczas gdy niechroniony około 1,7-1,8 razy. Na obydwu siedliskach i po każdym przejeździe ciągnika zrywkowego wskaźniki CI były istotnie statystycznie wyższe dla wariantu zrywki po gruncie nieosłoniętym. Dość istotny w procesie zagęszczania gruntu był pierwszy przejazd, podczas którego gleba nieosłonięta uległa zagęszczeniu w zależności od siedliska o około 35-51%, podczas gdy gleba osłonięta matą gałęziową o 11-21%. Po pierwszym przejeździe zestawu zrywkowego tempo wzrostu zagęszczenia gruntu było względnie stałe. Skonstruowano model regresji wielokrotnej (wzór 1), w którym zwięzłość gruntu w koleinach powiązano z typem siedliskowym lasu, liczbą przejazdów środka zrywkowego oraz obecnością narzutu gałęzi, wykazując przy tym, że największy wpływ na zwięzłość gruntu w koleinach miała obecność osłon gałęziowych. Przeprowadzone analizy pozwalają na zalecanie stosowania mat z pozostałości pozrębowych podczas zrywki nasiębiernej w celu ochrony gleby przed nadmiernym wzrostem jej zwięzłości.