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Influence of Ponsse Gazzelle forwarder passes on the soil environment and soil deformation.

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Abstract: During the harvesting and skidding process, machine runs have a strong influence on the soil environment. The study analyzed the influence of 20 runs of the Ponsse Gazzelle forwarder on the change of soil compactness, moisture and deformation. The research were carried out in Gidle Forest District, located in southern Poland. Analyzed areas was differing in soil type and hydrological conditions. On the investigated forest areas control sections were established for measurements.The data of changes in soil compactness were gained by using a handheld penetrometer at a depth of 10 and 20 cm. The soil compactnes were measured after each forwarder pass. Soil moisture was also assessed at a depth of 10 and 20 cm before the start of the forwareder operation, and after 20 passes. To obtain data for determining soil deformation UAV were used. Terrain models were created using Agisoft Metashape software. From the generated 3D terrain models, changes in the cross-sections of operational routes were determined.The data were subjected to statistical analysis to determine the relationship between the rate of changes in soil and terain conditions. The increase of soil compactness was linear on all the examined plots. Statistically significant differences were found in the soil compaction rate.After 20 runs of the forwarder, the humidity in the tested sections decreased almost 3 timesCorrelation analysis showed a moderate relationship with the extent of soil deformation and the type of soil
and the type of forest habitat.

Keywords: Forest Operations; UAV; Terrain 3D model; Wood Logging; Soil displacement

1. Introduction

The use of forwarders during forest work enabled a significant increase in the efficiency of timber transport from the harvesting site to the place of temporary storage. Due to their efficiency and greater safety compared to older types of machines, a further increase in the use of these machines in Polish forests seems inevitable[1,2].

Forwarders are characterized by high weight which makes their runs negatively affect the soil [3, 4] which results in soil compaction. Soil compaction is connected to decreasing soil porosity and increasing bulk density [5]. An increase in soil compactness is possible to measure by determination of soil penetration ressistance, by using penetrometer.

The development of technology and the increasing availability of unmanned aerial vehicles on the civil market, along with the growing offer of open-source programs for modeling based on aerial photos, opens up new possibilities for conducting analyzes of post-cut surfaces. [6,7,8].

The aim of the research was to analyze the influence of 20 forwarder runs on soil moisture and increase of its compactness. By using aerial photography and geomatic software, an analysis of the logging area, distribution and condition of the network of logging routes was carried out.

2. Materials and methods

The research was carried out in the Gidle Forest District in the southern Poland. For the study, 4 cutting areas were selected, differing in the type of soil, stand type and site wetness index (Tab. 1).

Table 1. Parameters of analyzed cutting areas.

Site nr.	Habitat type	Site moisture index	Soil type

1	BMW	++++	Bgms
2	BW	+++	Bgts
3	BMŚw	++	RDB
4	BŚW	+	Bw

Bśw – fresh coniferous; Bw – moist coniferous; BMśw – fresh mixed coniferous; BMw – moist mixed coniferous. Bw – podzolic soilBgms, Bgts -glial-podzolic soil, RDb - rusty podzolic soil

On each of analyzed sites, 30-meter-long control sections were established. On each of this test sections the changes in soil compactness were determined during 20 forwarder runs. The skidding process were carried out by the same Ponsse Gazelle forwarder, which was controlled by the same operator on all the analyzed areas.

Changes in soil penetration ressistance were measured with an Ejkelkamp hand penetrometer before skidding proces and after every of 20 forwarder passes. The measurements was made every 1 meter. Measurements were made in the left rut, right rut and in the lane between ruts. The changes in soil penetration ressitance were measured at a depth of 10 and 20 cm. Changes in soil moisture before starting work and after 20 forwarder passes were also determined.

Using an unmanned aerial vehicle (UAV), a flight was made over the analyzed cut areas, during which the photos were recorded. For the research a DJI UAV Phantom 4 Advanced model was used. This model is equipped with a camera with a 1-inch CMOS sensor and a resolution of 20 megapixels, allowing to take photos with a maximum resolution of 5472 × 3078 pixels. The flights were made at an altitude of 30 meters, and the overlap index of the photos was 80%, both horiontally and vertically.

The obtained photos were used to create digital elevation models [DEM] of the terrain and orthomosaic using Agisoft Metashape software. Obtained data allowed to create numerical models where a single pixel represents a square with a side of 1.5 cm in the terrain. By assesment of orthomosaics in Qgis te the skid trail area, lenght and codition was analyzed. By analyzing the DEM in Qgis software, the soil displacement and rutting depth during forestry work was determined.

R studio software was used to perform statistical analyzes. The Kruskal-Wallis test was used to determine the significance of differences between the studied surfaces. The correlation was calculated using Pearson correlation test.

3. Results and Disscussion

As noted by Walczyk and Kormanek [9], clear changes in soil compactness are visible at a depth of up to 25 cm. The most common analysis was the effect of different logging and skidding machines on soil in plots with similar characteristics. The less common form of research was the assessment of differences in the rate of changes of the compactness on the surfaces that differ in such parameters with the use of the same type of machine.

The course of changes in soil density showed a similar character in all tested sections, regardless of the tested depth. The areas in the BMSw habitat were characterized by the highest degree of soil compaction after 20 runs of skidding agent. The mean percentage change in compactness was also the largest on these plots.

The forwarder travels had a greater impact on the compactness of the soil at a depth of 20 cm than on the depth of 10 cm, regardless of the tested section on all tested surfaces.

In the left and right rut, the pace of increasing soil compaction was similar in all sections. In some cases, soil compactness increased almost 4 times at a depth of 10 cm and almost 5 times at a depth of 20 cm. The t test proven that there is statistically significant differences between soil density before and after 20 forwarder passes (p value = 0,0000).

At a depth of 20 cm, a greater ingresem in compactness can be noticed and that the forwarder wheels have a stronger impact on the ground between the ruts (Tab. 2).

Table 2. Changes in soil compactness [%] after 20 passes in relation to the state before the skidding for analyzed transects.

Placement	Depth	Transect			
		1	2	3	4
Left Rut		341.9%	418.7%	422.30%	341.9%
Middle	10 cm	208.4%	235.6%	273.90%	208.4%
Right Rut		325.9%	316.0%	431.40%	325.9%
Left Rut		385.4%	491.9%	341.20%	362.7%
Middle	20 cm	410.5%	394.3%	204.60%	394.3%
Right Rut		219.7%	283.0%	329.40%	313.4%

Soil moisture was determined by taking soil samples, and determining soil moisture by weighing and drying them. The change in soil moisture on the tested surfaces is summarized in the table below (Table 3).

Table 3. Soil moisture on the examined areas. .

Placement	Transect			
	1	2	3	4
Measure outside skid track (refrence)	42.20%	15.50%	13.70%	14.90%
Skid track before forwarder passes	37.30%	9.00%	8.60%	6.00%
Skid track after 20 forwarder passes	14.60%	5.80%	5.80%	3.90%

Machine travels noticeably lowered the water content in the tested soil. It is worth noting that the initial values on most surfaces are low from the very beginning. This is due to the fact that the research was conducted during a large drought durin summer in 2019.

Carrying out works with the use of forest machines should be performed in particular when the soil moisture is low. As proved by Buliński and Sergiel [10], the rate of compacting the same soil with the same parameters depends on the current degree of its moisture.

On the examined plots, differences were found between the area declared and the area measured on the basis of orthophotomaps (Table 4). There was an average of 0.91 km of skidding trails per 1 hectare of the studied site. These values are in the range of 0.67 to 1.00 km / ha (Table 4). During the research, the area of the operational routes was determined, on which deformation and damage to the soil structure caused by machine passes can be expected. Moreover, the area of places where machine runs caused the uncovery of the mineral layer of the soil were identified (Table 4.).

Table 4. Results of analyses based on orthomosaics in Qgis software.

Site	1	2	3	4
Area declared to cut	1.21	1.29	1.84	1.91
Area measured after cut	1.35	1.23	1.75	2.04
Diference [Ha]	0.14	-0.06	-0.09	0.13
Difference %	11.13%	-4.56%	-4.66%	6.70%
Skid trails lenght [km]	1.35	1.23	1.69	1.38
Skid trails per 1 Ha	1.00	1.00	0.97	0.67
Skid trails area [ha]	0.41	0.38	0.42	0.52
% of cut area covered with skid trails	33.72%	29.23%	21.85%	28.05%
Area with soil damage to the mineral layer [Ha]	0.053	0.007	0.05	0.055

Converted to % share in the area of the trails area	10.13%	1.50%	7.81%	10.24%
Converted to % share of measured cut area	3.92%	0.57%	2.85%	2.70%

Digital elevation model [DEM] is a numerical representation of the topographic height of the terrain surface. The topology is defined as a result of applying interpolation algorithms that recreate the shape of the modeled surface. Digital elevation models created on base of aerial photography were used to determine the rutting depth. Using the Qgis software and terrain profile plug-in, the depth of the ruts was determined and compared to the ground level around them. Large differences are noticeable in the depth of the ruts on the tested transects (Fig. 1.)

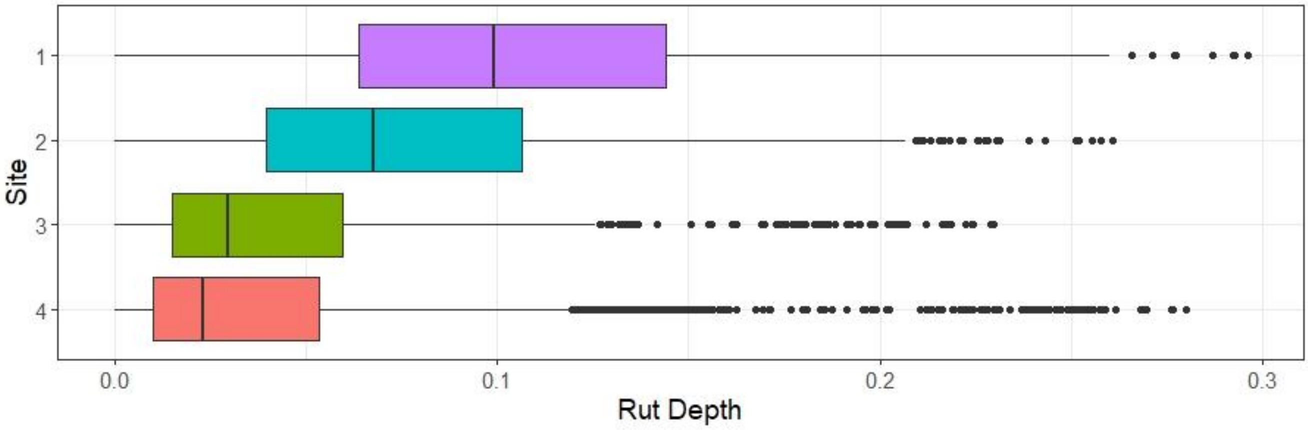

Figure 1. The result of rut depth analysis on the tested surfaces based on DEM in Qgis.

The kruskal-wallis test was used to assess whether there were any statistically significant differences between the depth of the ruts. The obtained result of p = 0.0000 indicates that there are statistically significant differences.

By carrying out the Pearson correlation test, the relationship between the tested surface and the size
of the created ruts was determined at the level of 0.44 which indicates a moderate correlation.

4. Conclussion

1. During the conducted research, differences in the rate of changes in soil compactness within the studied operational routes were found.
2. Soil moisture decreased in a similar manner for all the examined plots.
3. Differences were found between the area declared for cutting and the actual cut area.
4. The share of soil damage to the mineral layer did not exceed more than 4% of the examined areas.
5. Statistically significant differences were found between the size of the ruts formed on the individual examined plots.
6. A moderate correlation was found between the analyzed site and the size of the ruts after 20 forwarder passes.

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