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TIMBER FORWARDING FROM CROATIAN LOWLAND FORESTS – RUTTING AND SOIL COMPACTION

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Abstract: *This paper is a contribution to the studies of environmental evaluation of Timberjack 1710B forwarder on roundwood extraction from Croatian lowland forests. The research was carried out at 3 felling sites in the area of Gornja Posavina.*
The effects of forwarder work are shown as changes of physical-mechanical soil characteristics and water-air properties in the soil due to the load exerted on the soil by forwarders, width of tracking, rut depth and structure of tracking area.
Results of soil compaction raise doubts about environmental suitability of Timberjack 1710B forwarder use at the time of main felling, when moisture of hydromorphic soils in Croatian lowland forests is so high. The environmental suitability of the researched vehicle under said work conditions could be improved by using semi-tracks or by limiting vehicle's travel to skid-trail network with additional soil protection provided by covering skid roads with brushmates or by limiting the load volume.

1. Introduction and problem of research

Forest harvesting operations are accompanied by certain risks from damaging the forest ecosystem. The possibility of forest soil disturbance is highest on ground based extraction systems, due to vehicle constant contact with the ground. That is why, during their evaluation, special attention is always given to the complex interactions within the vehicle – soil – plant system. Consequences of vehicle movement throughout the stand are visible through soil tracking and compaction.

Soil tracking is a direct consequence of forest machinery movement during most mechanized forest management operations. Soil tracking is especially noticeable during the mechanized timber extraction, where heavily loaded vehicles pass once or multiple times along the same trail. Tracking surface varies significantly, from 15 to 30 %, but can in extreme situations occupy as much as 80 % of the cutting area surface (Wästerlund, 2002).

Relocation of soil layers, caused by vehicle movement, is manifested through ground hollowing (rut), upper soil layers removal and surfacing of the materials from deeper soil horizons (Arnup, 1999). Same author points out three most common negative consequences of soil layers relocation: surfacing of soil layers which creates unfavorable conditions for sprouting, plant growth and changes of species, exposure of mineral soil horizons to erosion and redistribution of soil material which reduces the accessibility of necessary nutrients.

Compared to rut depths, soil compaction caused by short-term pressure from vehicle's driving systems and dragging load is a much more complex manifestation. Soil compaction causes the collapsing of structural aggregates, reduction of interaggreagate spaces, pore quantity and soil volume, which results in deterioration of soil thermal regime and changes in soil's water-air properties, and partly obstructs the nourishment process that is necessary for the normal plant growth. Above all, soil compaction causes the reduction of uncapillary pores and soil's water permeability, which subsequently means that soil is developed under anaerobic conditions. According to Arnup (1999), susceptibility of forest soils to compaction is primarily determined by following factors: the size of vehicle's tyres or tracks, soil texture, soil moisture during the timber extraction, portion of skeletal and sand particles within the soil, soil structure, bulk density and porosity of the soil, natural soil compaction (depending on the geological origin), thickness and the origin of humus-accumulative layer.

Different measures for reducing the vehicle's pressure points on the soil are undertaken, with the goal of reducing the damages done on the soils with limited bearing capacity: use of vehicles with multiple wheels, double wheels on semi-axle, use of wider tyres and central tyre inflation system, use of chains on the front wheels and semi-tracks on forwarder's bogie axles, reduction of loaded or skidded roundwood, careful time planning for the execution of chosen operations (Bygdén, 2002; McDonald et al., 1996; Seixas and McDonald, 1997; Stokes and Schilling, 1997; Rumer et al., 1997; Saarilahti, 2002; Vechinski et al., 1998).

2. Scope and Method of Research

Main goal of this paper was to determine the environmental suitability of the, 17 tons heavy, Timberjack 1710B forwarder, during the timber extraction in Croatian lowland forests.

Determination of soil type and soil conditions was conducted by opening the pedological profile (soil type and soil horizons pattern), gathering samples from disturbed (grain size distribution) and undisturbed soil (100 cm^3 sample cores) and measuring two of soil's physical-mechanical characteristics: cone index by using WES penetrometer and soil strength by using the share vane. Soil moisture was measured with a ThetaProbe ML2 moisture meter. ThetaProbe is designed to measure volumetric soil water content using the Frequency Domain Reflectrometry technique. Cone index and soil strength measuring was conducted at 15 cm deep soil (ASAE EP542, 1999). Sample cores were taken from the same soil depth (standardized by cone index). Samples gathering from tracked and untracked soil was conducted in accordance with the rules from the "Manual for soil testing" (Anon., 1971). Soil samples analysis was performed at the pedological laboratory of the Faculty of Forestry in Zagreb, in accordance with the "Manual for pedological researches" (Škorić, 1982). Soil tracking (% of the total felling area surface) was determined by using the GPS instrument (GeoExplorer 3). Instrument's antenna was installed on the forwarder's cabin roof, and soil tracking structure was calculated through the analysis of the gathered samples, using the GIS application (ArcView). Rut depth was measured by using the 5 m long geodetic lath, placed on the anchored props.

Level of damages on the forest soil during the timber extraction, dependent on the number of forwarder passes along the same place, will be expressed through: felling unit's tracking surfaces structure, soil compaction visible through changes in soil's physical-mechanical characteristics (cone index and soil strength), water-air properties (bulk density, solid density, porosity, water capacity and soil air capacity) and rut depth.

3. Places of Research

Research on environmental suitability of the Timberjack 1710B forwarder, during the roundwood extraction operations, was conducted at 3 felling sites in lowland pedunculate oak forests in the area of Gornja Posavina. Brief overview of soil characteristics in the researched cutt-blocks is shown in table 1.

Due to the increased soil moisture on cutt-block 44b, MU Žutica, forwarder was additionally equipped with semi-tracks and its movement was limited to the skid trail network. Trails were 20 meters apart, and were covered with layer of branches that served as additional protection for the soil. On cutt-block 14a, MU Josip Kozarac, forwarder was driving along the existing trails, that were 130 meter apart from each other, and only entered interspaces for the loading of roundwood. As there aren't any secondary roads in cutt-block 24b, MU Obreški Lug, main characteristic of roundwood extraction during the thinning operations in this area was the unlimited forwarder movement along the cutt-block.

Table 1: Soil features of research cutt-blocks

	Sječine – *Cutt-blocks*		
Forest office	Novoselec	Remetinec	Lipovljani
Management unit	Žutica	Obreški Lug	Josip Kozarac
Subcompartment	44b	24b	14a
Felling type	final	thinning	final
Type of soil	gleysol amphygleyic	planosol	planosol
Grain size distribution*	clay	loam	clay
Sand, %	34,1	38,5	28,8
Silt, %	31,9	43,9	40,3
Clay, %	34,0	17,6	30,9
Physical-mechanical soil characteristics*			
Soil cone index, MPa	0,61 ± 0,36	2,52 ± 0,65	0,92 ± 0,31
Shear strength, kPa	76 ± 28	205 ± 83	152 ± 31
Current soil moisture, vol. %	50,4 ± 6,8	17,1 ± 2,8	43,1 ± 5,7
Water-air soil properties*			
Bulk density, g/cm^3	1,10 ± 0,06	1,01 ± 0,0,08	1,11 ± 0,10
Solid density, g/cm^3	2,60 ± 0,06	2,57 ± 0,06	2,57 ± 0,03
Soil porosity, vol. %	57,5 ± 2,5	60,5 ± 2,5	56,7 ± 3,8
Water capacity, vol. %	51,0 ± 3,5	46,7 ± 2,5	46,5 ± 5,6
Air capacity, vol. %	6,5 ± 2,7	13,8 ± 1,7	10,3 ± 4,4

* values on the soil depth of 15 cm

4. Research Results

The effects of forwarder work are shown as changes of physical-mechanical soil characteristics and water-air properties in the soil due to the load exerted on the soil by forwarders, width of tracking, rut depth and structure of tracking area.

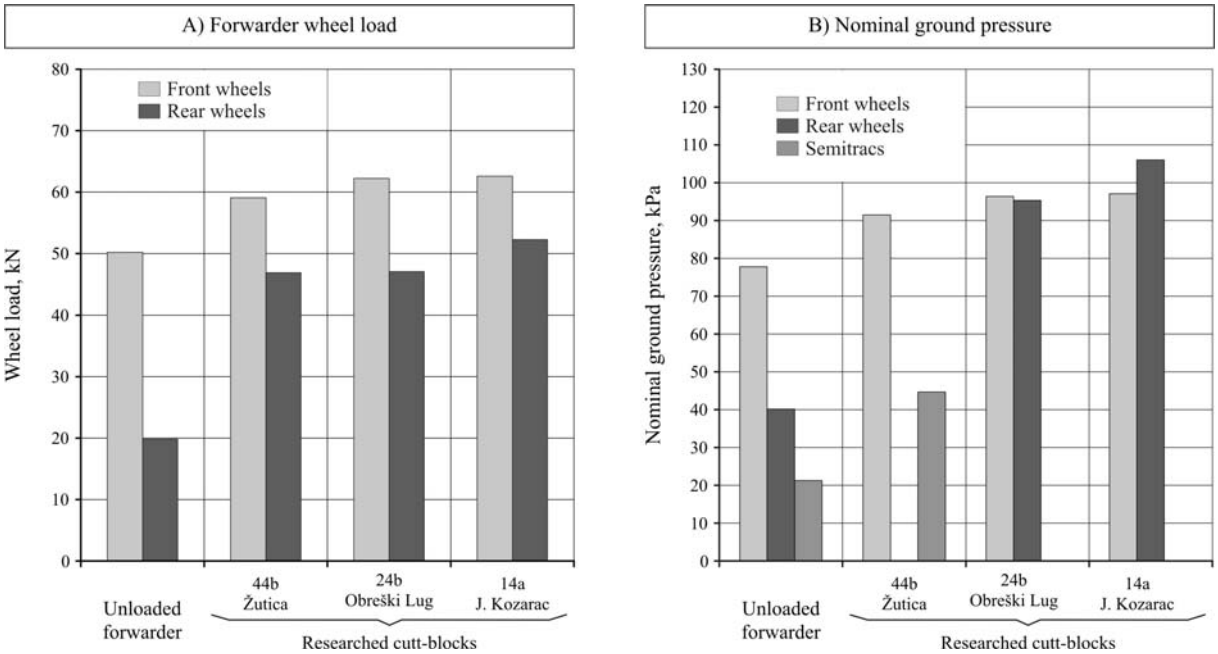

Figure 1: Wheel loads and nominal ground pressure

Changes in the soil, caused by multiple forwarder passes, should be considered in relation to general pedological characteristics of the forest soils in the observed felling units, soil moisture at the moment of the research (Table 1) and pressure on the soil from forwarder movement (Fig. 1A). Vehicle's nominal pressure on the ground (Mellgern, 1980) was chosen as the parameter that best describes the forwarder's contact pressure on the soil. Average values of nominal ground pressures from forwarder's front and rear drive shafts are shown in figure 1B.

4.1. Changes of physical-mechanical soil characteristics

Soil compaction, caused by multiple vehicle passes along the same place, was researched by measuring the two physical-mechanical soil characteristics: cone index by using the WES penetrometer (Fig. 2A) and soil strength by using the share vane (Fig. 2B).

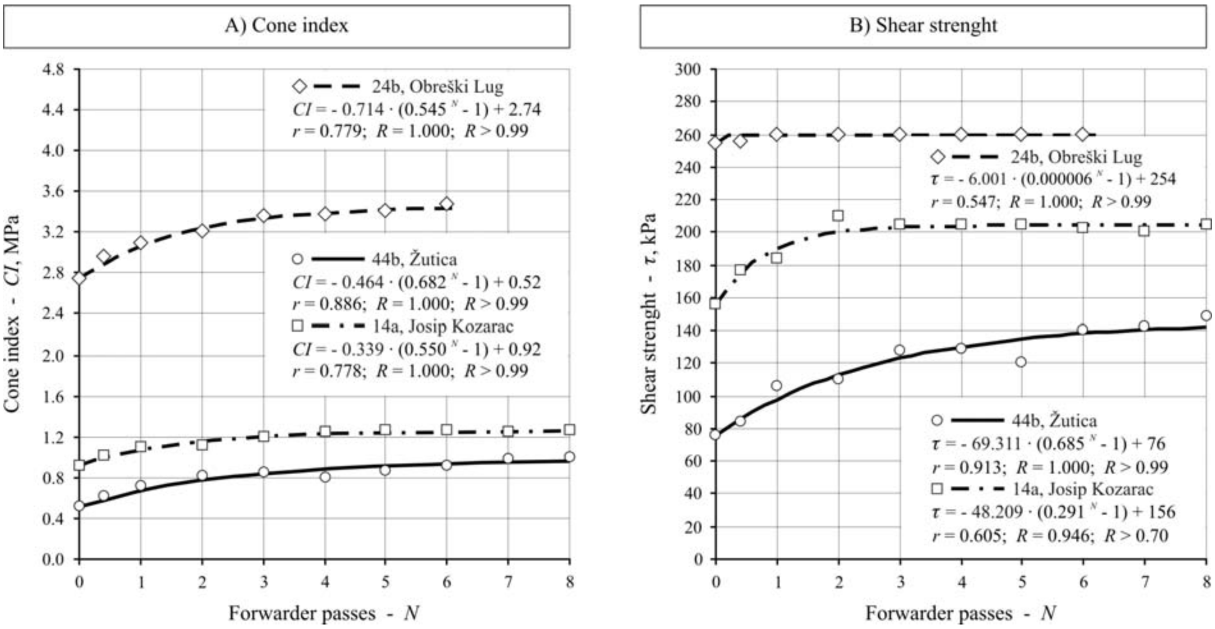

Figure 2: Changes of physical-mechanical soil characteristics

Based on the results of cone index and soil strength measuring, in dependence to the number of forwarder passes, the following was concluded:

- ⇒ cone index and soil strength measured values, on the untracked soil, are dependent on soil's bulk density and its current moisture,
- ⇒ by comparing the results from measuring cone index and soil strength on untracked and tracked soil, it is possible to determine the level of soil compaction in relation to the number of vehicle passes,
- ⇒ results from measuring indicate the higher soil sensitivity to compaction, in the conditions of increased soil moisture (44b, MU Žutica, 14a, MU J. Kozarac),
- ⇒ the highest level of soil compaction, visible through the increase of soil's physical-mechanical characteristics, was determined after the first vehicle pass, and after the further passes increase of values started to decline gradually,
- ⇒ forwarder movements on the layer of branches and usage of semi-tracks decreased the level of soil compaction, regardless of the high soil moisture (44b, MU Žutica).

4.2. Changes of water-air soil properties

Soil compaction caused by multiple forwarder passes along the same trail is also visible through changes in soil's water-air properties (Fig. 3), which are crucial for soil fertility and plant growth.

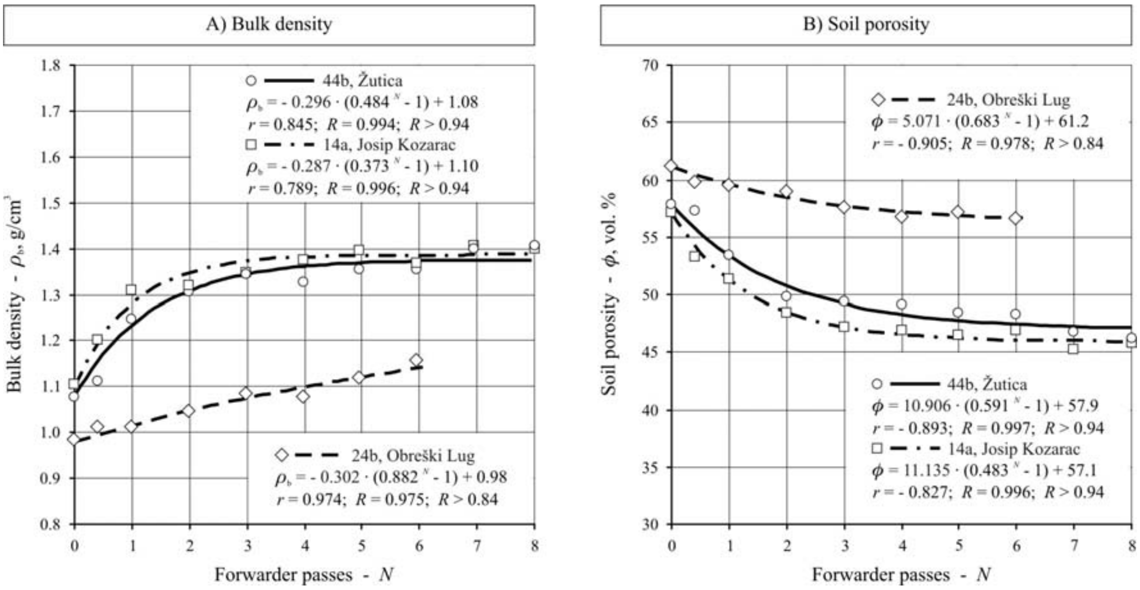

Figure 3: Changes of water-air soil properties

Laboratory analysis of soil samples from undisturbed soil (sample cores) determined the following changes in soil's water-air properties:

- ⇒ by comparing the increase of bulk density (Fig. 3A) and the decrease of soil porosity (Fig. 3B), in dependence to number of loaded forwarder passes on felling sites with drier soil (24b, MU Obreški Lug) to felling sites with partially moist soil (14a, MU J. Kozarac) or completely moist soil (44b, MU Žutica), it is visible that soil's sensibility to compaction grows with its moisture,
- ⇒ allowed porosity decrease, which amounts to 10% of the untracked soil porosity (Froelich 1989), was determined right after the first loaded vehicle pass on sites with increased soil moisture, while, on the site with dry planosol, allowed decrease wasn't determined even after six loaded forwarder passes,
- ⇒ single ANOVA analysis didn't show statistically significant differences in solid density between control measuring on untracked and tracked soils,
- ⇒ all soil's water-air characteristics, except solid density, indicate that highest soil compaction occurs after the first forwarder pass. Furthermore, decrease or increase of water-air characteristics values is dependent on soil conditions in the researched felling sites. Slower decrease of water-air characteristics values was determined after the increased number of vehicle passes along the same place.
- ⇒ based on the research results collected in the conditions of higher moisture and limited bearing capacity of the soil, usage of semi-tracks on the vehicle's rear bogie axle is recommended. Usage of semi-tracks in the above mentioned conditions insures the easier forwarder movement and reduction of nominal pressure to the ground, which, in the end, results in lower level of damages done to the soil.

4.3. Width of soil tracking and rut depth

Soil tracking width on the researched felling sites was divided into soil tracking width of forwarder's driving system (tires on the wheels, semi-tracks) and vehicle's soil tracking width that includes the spaces between forwarder's driving system.

Soil tracking width of forwarder's driving system depends on the width of forwarder's front tires (700/70-34) or the width of semi-tracks (90 cm). Vehicle's soil tracking width is additionally divided into the width of single and multiple vehicle passes (Fig. 4D). Soil tracking width of single vehicle pass is determined by forwarder's width (3.05 m), which increases to 3.26 m with the usage of semi-tracks.

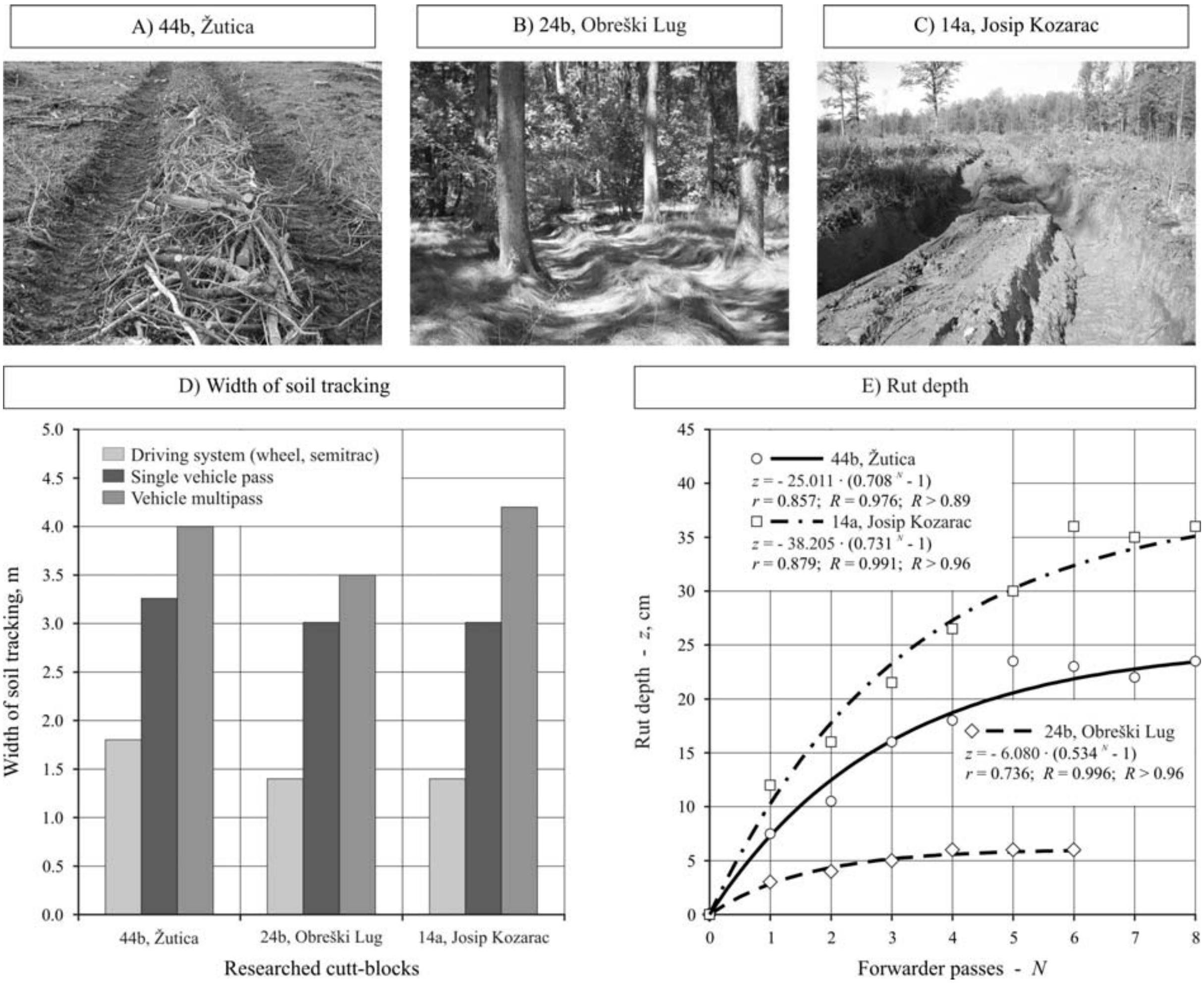

Figure 4: Width of soil tracking and rut depth

Multiple forwarder passes along the same trail caused the increase of tracking width, which was approximately 4 m (44b, MU Žutica), 3.5 m (24b, MU Obreški Lug) and 4.2 m wide (14a, MU Josip Kozarac). Given results were influenced by interaction between used forwarder driving systems, limited forwarder movement on the layer of branches and soil's bearing capacity at the researched sites. Data on soil tracking widths will be used for determining the total disturbed surface in the researched cut-blocks.

Results of rut depth measuring indicate the dependence on interaction between soil bearing capacity and soil strain caused by forwarder's driving system. Increase of rut depth, caused by multiple forwarder passes, is in consistence with the soil bearing capacity of the researched felling sites. Lesser rut depth has been observed on the felling sites with higher moisture, where forwarder movement was limited to the trails covered with the layer of branches and usage of semi-tracks was obligatory (Fig. 4E).

Lowest rut depth values have been recorded on high bearing capacity planosol (CI/NGP = 6.2) in the compartment 24b, MU Obreški Lug. It is also important to point out the fact that, even after six loaded forwarder passes, the allowed rut depth limit (<10 cm) hasn't been exceeded.

Higher exponential increase of rut depth values, in dependence to the number of forwarder passes, has been recorded in cutt-block 14a, MU Josip Kozarac, with low moisture planosol, compared to cutt-block 44b, MU Žutica, with high moisture gleysol. Cause of such results is the usage of semi-tracks and forwarder movement on the layer of branches at cutt-block 44b, MU Žutica, which reduced the nominal pressure on the ground (CI/NGP = 2), but also the higher nominal pressure of forwarder's wheels (CI/NGP = 2,2) caused by higher average load volume (13.6 m^3/load) on the cutt-block 14a, MU Josip

Kozarac. Unallowed rut depth (>10 cm) on the above mentioned cutt-blocks has been recorded after second loaded vehicle pass.

4.4. Structure of tracking area

Consequences of Timberjack 1710B forwarder movement on stand conditions are visible through soil tracking on researched felling sites. Data on vehicle movement, gathered by using the GPS instrument, has been analyzed using the GIS application. Soil tracking area is presented in two ways: as vehicle's soil tracking area and forwarder's driving system soil tracking area.

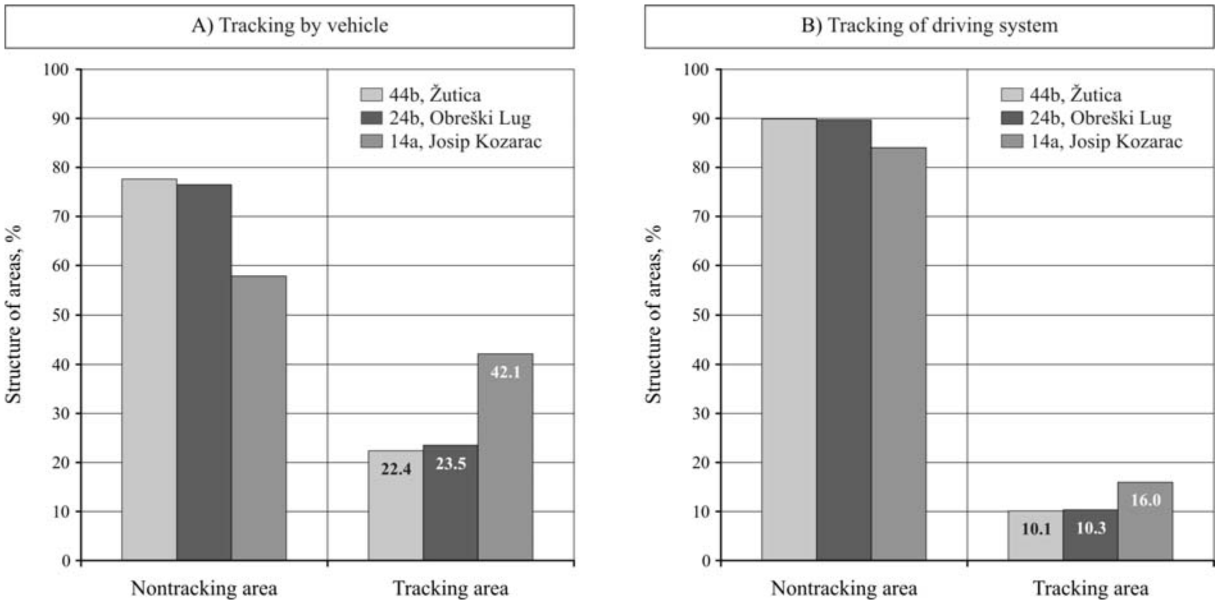

Figure 5: Soil tracking

Dual results on soil tracking (which delimited area width in GIS application should be set around vehicle movement vector) emerged as a consequence of inadequate definition of the term “soil tracking” in professional literature, but also due to certain cognitions deduced from conducted researches (Fig. 4). In cases with favorable soil bearing capacity, forwarder movement does not cause damages to the soil surface between vehicle’s wheels (fig. 4B). But, results are totally opposite in cases with multiple, or even single forwarder passes on soils with unfavorable bearing capacity (Fig. 4C). Additional problem on soils with unfavorable bearing capacity emerged when, even though semi-tracks were used and forwarder movement was limited on trails covered with layer of branches, vehicle still made a large indent in the ground (Fig. 4A).

Vehicle’s soil tracking area above 22 (40) % (Fig. 5A) and forwarder's driving system soil tracking area above 10 (16) % (Fig. 5B) has been determined on all researched felling sites.

Present systematic installation of skid trail networks (3 m wide and 37.5 m apart) in young stands, represents a good start towards the future reduction of soil tracking during the harvesting operations in lowland forests. In theory, such interspaces between the future trails, and directed (vertical) felling of trees towards the trail, should significantly reduce the vehicle’s soil tracking area as well as the forwarder’s driving system tracking area.

5. Conclusions

Results of soil tracking and compaction raise doubts about environmental suitability of, 17 tons heavy, Timberjack 1710B forwarder usage at the time of main felling, when moisture of hydromorphic soils in Croatian lowland forests is high.

The environmental suitability of the researched vehicle under given work conditions could be improved by using semi-tracks or by limiting vehicle's travel to skid-trail network with additional soil protection provided by covering skid trails with brushmates or by limiting the load volume.

The environmental suitability of the researched forwarder could also be improved by using the central tyre inflation system, dependent on current forest soil conditions. Research of these possibilities is a future task for all forest scientists involved in problems related to consequences of vehicle movement on forest soils.

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