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ENVIRONMENTAL EVALUATION OF WOOD RESIDUES UTILIZATION

Zdravko Pandur, Dubravko Horvat, Marijan Šušnjar, Hrvoje Nevečerel, Igor Stankić

Institute of Forest Engineering, Faculty of Forestry, University of Zagreb
Svetošimunska 25, 10040 Zagreb, Croatia
e-mail: pandur@sumfak.hr - horvat@sumfak.hr - susnjar@sumfak.hr
nevecerel@sumfak.hr - stankic@sumfak.hr

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Abstract: *The paper deals with environmental evaluation of two different harvesting methods of wood residues utilization. In the research, all harvesting volume, which is not technical roundwood, is defined as wood residues. According to this definition, wood residues consist of small sized roundwood (fuelwood) and branches. Research was carried out in two subcompartments of the same forest compartment, representing forest stand of pedunculate oak in the lowland part of Croatia.*
At first, technical roundwood was extracted by forwarders in each subcompartment. After that, wood residues were extracted by forwarders in the first subcompartment. Traditional method of wood residues utilization was applied in the second subcompartment, which comprises processing of fuelwood to 1 m length by chainsaws, extraction of fuelwood by tractor and semitrailer and bunching of branches on stumps without utilization.
Environmental evaluation of two different harvesting methods of wood residues utilization was based on wheel numeric (N_w) – parameter which describes interaction between wheel load and soil. Cone penetrometer for measuring soil bearing strength, shear vane for measuring soil shear strength and platform scale for measuring wheel loads of vehicles were used in the investigation.
The results pointed out more extensive soil damages during traditional wood residues utilization with extraction by tractors and semitrailers. Wheel loads of tractor and semitrailer are lower than wheel loads of forwarder during extraction of fuelwood. However, wheel dimensions of tractor and semitrailer are smaller, especially tire width, which leads to the smaller wheel-soil contact area and smaller value of wheel numeric. Also, a greater percentage of tracking area was noticed during extraction of fuelwood by tractors and semitrailers.

1. Introduction

When harvesting wood in Croatian lowland forests, extraction of wood is usually carried out by forwarders and tractors with semitrailer. Forwarders, as special forest vehicles of the third generation, are mostly used in Croatian lowland forests for extracting wood assortments of the main felling, and tractor assemblies of thinning.

In Croatian lowland forests, which are characterized by frequently excessive soil wetting, the current soil moisture is the key factor of soil bearing strength, and hence also the key factor for performing forest operations. The effect of increased soil moisture is the decrease of its bearing strength, which results in a restricted maneuverability and reduced production, and also in increased damage to soil in the form of its compaction and formation of wheel ruts. Only soil compaction, caused by off-road vehicle travel, causes increased soil density i.e. lower pore content. Decrease of pore content is closely related to the decrease of soil water permeability or soil air capacity, which affects the soil fertility and consequently also the growth of plants. Due to increased soil moisture of lowland forests in Croatia during the whole year (Anić 2001), they are classified as sensitive forest stands. Ward and Lyons (2000) determine sensitive forest stands as stands where usual procedures of wood harvesting have to be modified so as to avoid damaging effects on ecological, economic and social functions of forest. It can therefore be concluded that vehicles with the lowest possible numeric are the most appropriate for extracting wood in lowland forests of Croatia.

This paper deals with the comparison of ecological suitability between forwarder and agricultural tractor with semitrailer in extracting forest residues under specific conditions in Croatian lowland forests. Furthermore, the paper also deals with the issues of calculating the wheel numeric considering the fact that parameters such as contact area and cone index may have a wide range of values.

The assessment of environmental suitability of forwarders based on wheel numeric was described by Šušnjar et al. (2006) by use of theoretical forwarder load.

Field research was carried out in a typical sub-Panonian lowland forest of pedunculate oak in the region of East Slavonia. The soil, widely spread over the researched area, belongs to the group of hydromorphic soils that are characterized by excessive wetting in a part of the soil profile or in all of it.

2. Materials and methods

WES Method (*Waterways Experimentation Station, US Army Corps of Engineering Research*) of assessment of vehicle maneuverability is based on wheel numeric – N_W, which is defined as the ratio between the wheel-soil contact pressure and soil bearing strength measured by penetrometer. Generally speaking, the wheel numeric can be easily calculated. According to a general expression (1), which is usually used, it is necessary to measure (calculate) three basic parameters: *CI* – cone index, *A* – wheel-soil contact area and G_w – wheel load.

$$N_w = \frac{CI \cdot A}{G_w} \tag{1}$$

For measuring soil penetration features, i.e. cone index – *CI* at a soil depth of 15 cm (standard ASAE EP542 1999), a digital penetrometer *Eijkelkamp Penetrologger* was used with the surface area cone of the circular base of 2 cm^2 and point angle of 30º. Cone penetration into soil was performed up to the depth of 80 cm. During each pass of the vehicle in the same wheel ruts, penetration features were measured on both wheels, between wheel ruts and on undisturbed soil outside wheel ruts.

Wheel/soil contact area was calculated from a general expression (2) (Mellgreen 1980) based on known tire dimensions: diameter of unloaded tire – *r* and breadth (width) of unloaded wheel tire – *b.*

$$A = r \cdot b \tag{2}$$

The said expression theoretically restricts a wide use of this model because it gives an approximate length of the loaded wheel contact area, at the wheel rut depth of 30 cm, with the wheel diameter. The advantage of this expression is its simplicity.

Vehicle wheel load G_w, or vehicle axle mass was measured by portable scale system WLS 101/RK (BARK System-und Wiegetechnik GmbH & CO.KG), which was mounted on steel platform for providing easier measurement on uneven ground (Fig. 1B). Portable scales WLS 101/R2K are electrically-mechanically operated, their weighing capacity is 10 t per scale (in total 20 t), and the breakage resistance is 150 % of the highest load.

Figure 1. Cone index measuring and weighing of forwarder front axle at the platform with axle scales

3. Results of research

According to WES method which estimates the quality of vehicle maneuverability breaking it down into three maneuverability classes, uses wheel numeric for correlating vehicle tractive features and soil deformations with soil bearing strength, in this Table 1 the obtained results of wheel numeric are in a good maneuverability class where $N_w > 3$.

Table 1. Wheel numeric and parameters necessary for its calculation for both vehicles.

	Forwarder *Valmet 840.2*		Tractor *Belarus 820*		*Semitrailer*
	Front wheel	Bogie	Front wheel	Rear wheel	
CI (MPa)	1,11		0,93		
m (kg)	4.254	8.372	528	1.807	3.617
G_w (kN)	41.73	82.13	5.18	17.72	35.48
A (m^2)	0.46878	0.792	0.13	0.3195	0.1628
NGP (kPa)	89.02	103.70	39.85	55.47	217.85
N_w	**12.47**	**10.7**	**23.34**	**16.77**	**4.27**

Code index:
m – wheel mass, kg
G_w – wheel load of vehicles, kN
A – contact area, m^2
NGP – nominal ground pressure. kPa
N_w – wheel numeric

Table 1 shows that referent wheel at forwarder is the bogie wheel and at tractor with the semitrailer referent wheel is wheel on semitrailer as proposed by Saarilahti (2002a).

Cone index necessary for the calculation was derived from the arithmetic mean of all penetration features measured on unloaded soil at the depth of 15 cm (Fig. 2A). The present diagrams show high dispersion of measured data right due to inhomogeneity of the forest soil, which is interwoven with the skeleton of forest trees roots. Due to this problem, the last graph (Fig. 2D) shows a large range of the measured cone indexes from minimum to maximum values, from 25 to 75%, position of medians and arithmetic mean and gamma distribution of number of observations for the category of investigated soil.

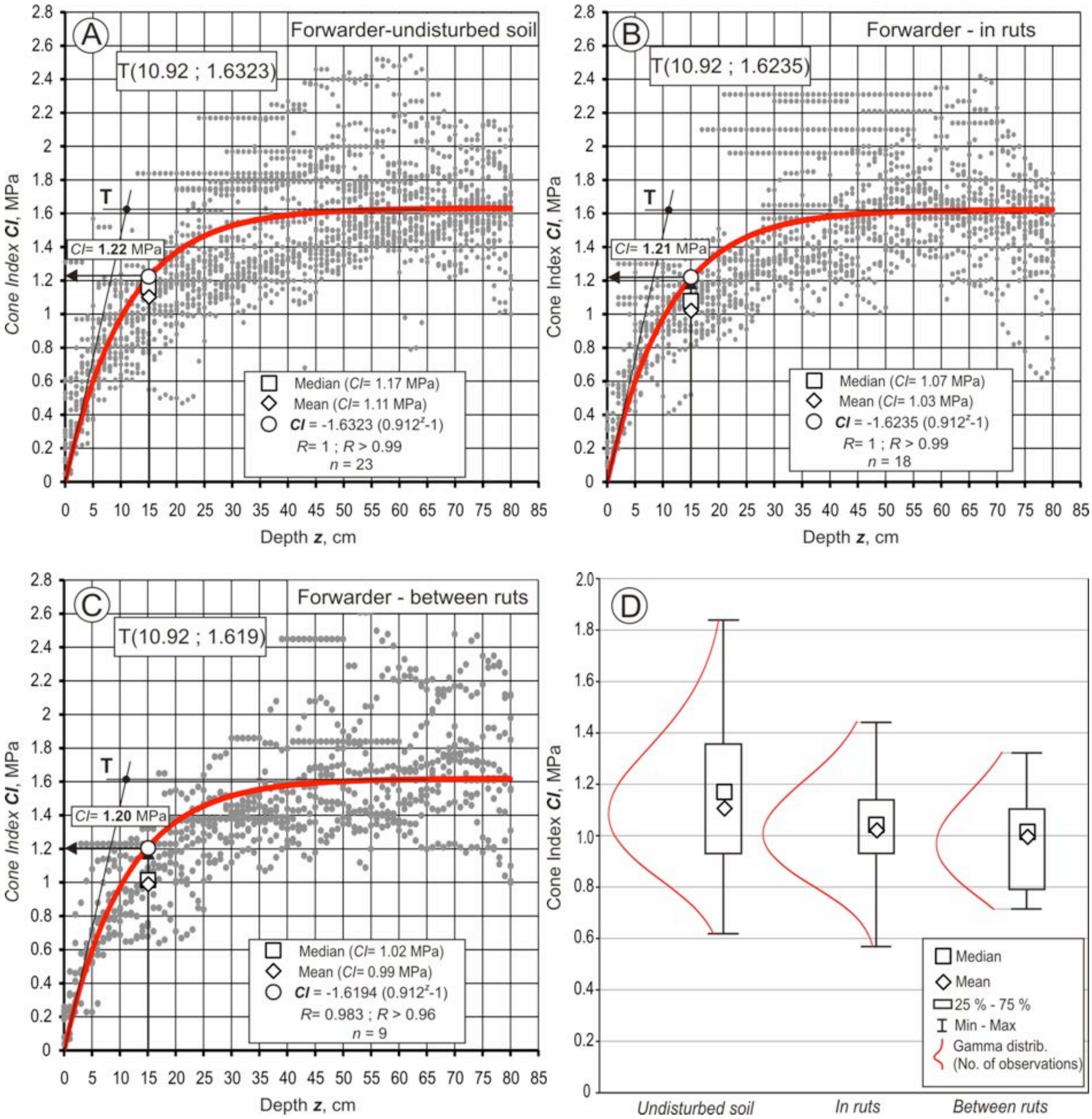

Figure 2. Review of penetration features and distribution of number of observations for all three categories of investigated soil during extraction of forest residues by forwarder.

So as to obtain an, as much as possible, accurate value of the cone index, which is a key parameter for calculating the wheel numeric, the need arose for statistical processing of the measured data, by which the values of cone index that, according to a specific statistical model, failed to satisfy the final value of cone index derived from the arithmetic mean of the remaining data, would be rejected. Diagram D in Fig. 3 shows a disproportion of data according to gamma distribution of observations and in such cases a certain statistical model is necessary for getting satisfactory arithmetic mean of the cone index. The other possibility is to cancel the measurement if during the penetration test the cone runs into an obstacle in the soil, and in such case only measurements in which foreign resistances in the soil do not appear are taken into account.

It can be seen in diagrams A and B presented in Fig. 3 that the arithmetic mean of the cone index of undisturbed soil is unexpected higher than that of compacted soil. One of the reasons can be the broken structure of the soil layer in which the cone index (15 cm) is measured during forwarder operation, while the other reason can be in the inhomogeneity of forest soil. Due to such uncertainties it is truly necessary to make either a statistical processing of the measured data or to cancel the measurements in which resistances appear in the soil caused by roots of forest trees. It should be taken into consideration that the soil skeleton increases its bearing strength, and also the possibility of providing tractive force as shown by Wasterlund (2003).

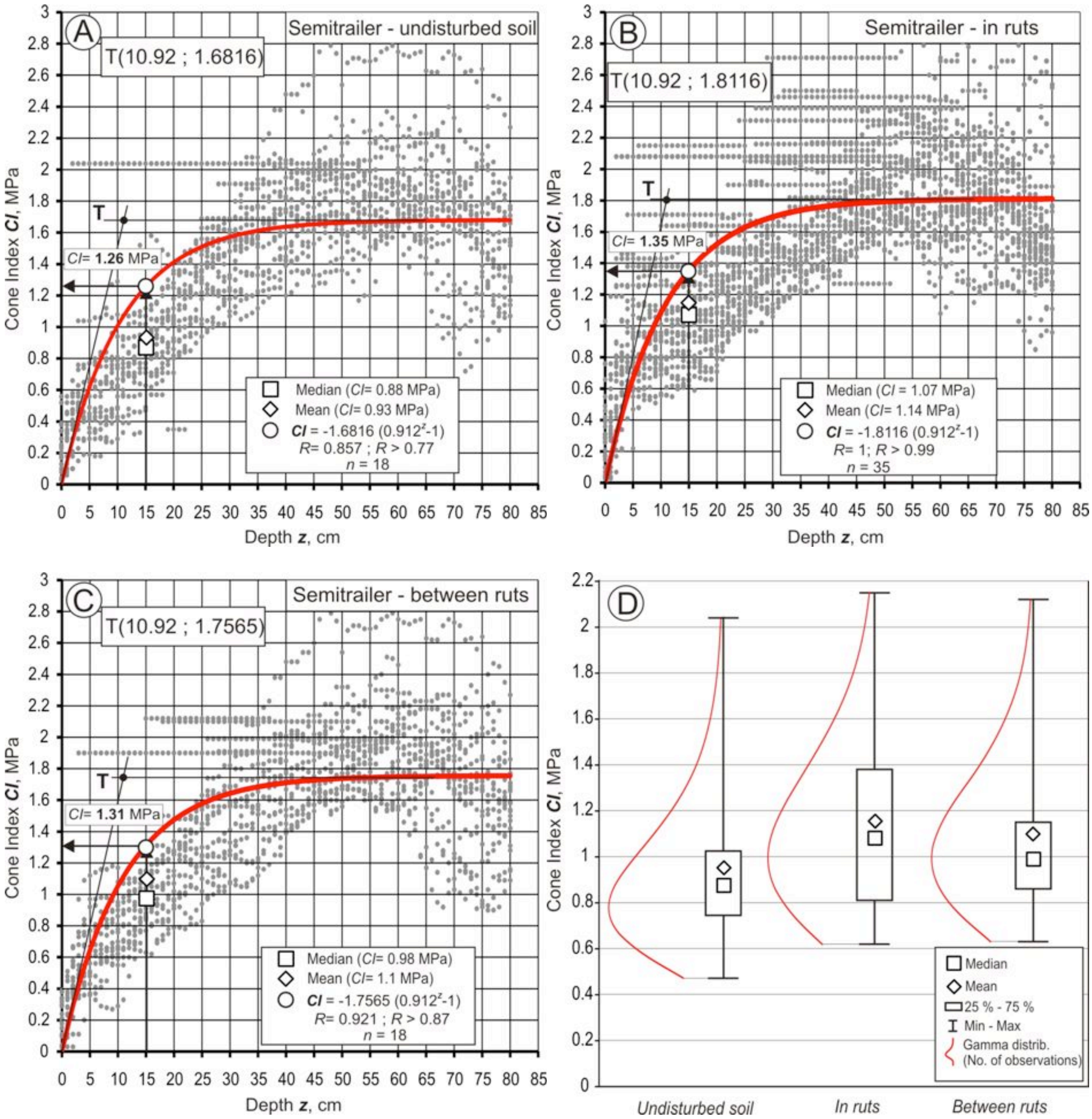

Figure 3. Review of penetration features and distribution of number of observations for all three categories of investigated soil during transport of cut wood from the forest by agricultural tractor and semitrailer.

An additional problem that appears in calculating the wheel numeric is the problem of correct calculation of wheel-soil contact area. It has been already mentioned above that the expression by Mellgren (1980) was used due to its simplicity and the question is whether the value of the area obtained by this expression satisfies our needs considering the above said deficiencies. There are many authors dealing with the issue of wheel-soil contact area, and some of them are listed in Table 2 along with the expressions used for calculating the contact area of front and rear wheels of the tested forwarder. According to this Table, it can be seen that the calculated contact areas differ considerably one from another, and with some expressions the difference between areas is more than 4 times higher for the same wheel. According to the calculated values for both wheels, the expression used by Mellgreen (1980) gives medium values compared to other expressions and hence it is considered appropriate for calculating the wheel numeric.

Table 2. Review of most frequently used expressions for calculating wheel-soil contact area and their value for forwarder wheels.

Expression	Contact area of forwarder tires - *A* [m^2]	
	Front wheel *NOKIAN TRS L-2 600/65 - 34*	Bogie *NOKIAN TRS LS-2 600/55 - 26.5*
Maclaurin (1997): $A = b_k^{0.8} \cdot d^{0.8} \cdot \delta^{0.4}$	**0.286541**	0.173537
Turnage (1972): $A = b \cdot d \cdot \sqrt{\frac{\delta}{h} \cdot \frac{1}{1 + \frac{b}{2 \cdot d}}}$	0.299274	**0.161333**
Freitag (1965): $A = b \cdot d \cdot \sqrt{\frac{\delta}{h}}$	0.356923	0.198
Rowland (1972): $A = b^{0.85} \cdot d^{1.15} \cdot \left(\frac{\delta}{h}\right)^{0.5}$	0.411824	0.222858
Mellgreen (1980): $\boldsymbol{A = r \cdot b}$	**0.46878**	**0.396**
Brixius (1987): $A = b \cdot d \cdot \left[\frac{1 + \left(5 \cdot \frac{\delta}{h}\right)}{1 + \left(3 \cdot \frac{b}{d}\right)}\right]$	0.750058	0.439788
Wismer and Luth (1973): $A = b \cdot d$	**0.93756**	**0.792**

Code index:
A – contact area, m^2
r – radius of unloaded wheel tire, m
d – diameter of unloaded wheel tire, m
δ – wheel tire deflection, m
h – height of tire profile, m
b_w (*b*) – breadth (width) of unloaded wheel tire, m

If the lowest, medium and the highest value of the cone index from Fig. 2A and the lowest, medium and the highest values for the area from Table 2 were inserted into the expression for N_w (3), then the values of the wheel numeric for forwarder bogie would range between 4.32 and 23.47.

$$N_{w(Forwarder)} = \frac{CI^{\,max}_{\substack{mean\\min}} \cdot A^{\,max}_{\substack{NGP\\min}}}{G_w} = \frac{CI^{\,1.22}_{\substack{1.17\\1.11}}\,\text{MPa} \cdot A^{\,1.58}_{\substack{0.79\\0.32}}\,\text{m}^2}{82.13\ \text{kN}} = \begin{matrix}23.47\\11.25\\4.32\end{matrix} \qquad (3)$$

According to the presented results, it can be seen that the wheel numeric between the minimum and maximum values is even higher than 5 times. These are large differences and a more reliable method for its determination should be found.

Figure 4. Part of stand with lower soil bearing strength compared to the remaining area

4. Discussion with conclusions

It can be seen from the values of wheel numeric that in the given favorable soil conditions, both tested vehicles can be classified into a good manoeuvrability class according to WES method. The lowest wheel numeric was calculated with semitrailers due to lower dimensions, or lower wheel-soil contact area. In order to increase the wheel-soil contact area and at the same time decrease the wheel-soil contact pressure in case of higher soil moisture (Fig. 4), bogie axle should be mounted instead of one axle on similar semitrailers.

The cone index, as a relatively simple parameter, does not seem reliable enough according to the obtained results in Fig. 2 and 3. In order to get values of the cone index, as accurate as possible, some statistical methods should be used for separating only the data without extreme or maximum measured values of the cone index. The said statistical processing is the problem to be solved in future researches. The other solution would be to reject the measurements in which a soil obstacle is met in future field measurements, but the question arises whether the soil bearing strength would then be well assessed.

The next problem is to determine precisely the wheel-soil contact area. As shown in Table 2, this area differs considerably from one author to another and therefore NGP (Nominal Ground Pressure) is recommended according to the expression (2) of Mellgreen (1980).

The presented results are only part of comprehensive field researches.

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