Effect of Bogie Track and Slash Reinforcement on Sinkage and Soil Compaction in Soft Terrains

Yuri Gerasimov, Vasily Katarov

Abstract – Nacrtak

A study of the effect of bogie wheel track and slash reinforcement on the sinkage (as rut depth) and soil compaction (as bulk density) of silt loam soil was carried out in spring and autumn at two harvesting sites in Russia. A Ponsse ELK forwarder loaded with 16 m^3 of timber, fitted and unfitted with bogie tracks, was repeatedly driven on forest soil for 1–10 passes. The degree of sinkage and soil compaction was measured at two soil moisture contents: moist (W = 80%) and wet (W = 93%) after each pass. A John Deere 1410 forwarder loaded with 16 m^3 of timber, and fitted and unfitted with bogie tracks, was driven on forest soil covering a 15 kg/m^2 slash layer for 1–10 passes. The degree of soil compaction was measured at moist soil (moisture content W = 88%). The results indicated that on forest silt loam soil the bogie track decreases sinkage in comparison with a conventional wheel with a tire: the maximum rut depths reached were 0.48 m vs. 0.71 m (–0.23 m) on wet and 0.22 m vs. 0.40 m (–0.18 m) on moist soils by the 10^{th} pass (160 m^3 of extracted timber), respectively. The track influence on soil compaction varied and was mixed. Bulk density increased up to 1.30 g/cm^3 vs. 1.24 g/ cm^3 (+0.06 g/cm^3) on moist soil and it was almost the same on wet soil by the 10^{th} pass, respectively. The slash reinforcement constrained rut-forming and soil compaction after all forwarder passes. Cubic regressions between average rut depth and bulk density and cumulative volume of extracted timber were derived for forest silt loam soil with different moisture contents. Bogie track and particularly slash reinforcement are necessary for environmentally sensitive wood harvesting by the CTL system on soft soils.

Keywords: CTL, forwarder, rut depth, bulk density, slash, bogie track, Russia

1. Introduction – *Uvod*

The fully mechanized cut-to-length (CTL) wood harvesting system, based on a single-grip harvester and a wheel forwarder, has become more common in Russia (Gerasimov et al. 2008). Many reasons are given for this statement, including reduction in labor requirements, work safety risks, environmental damage, and landing areas in comparison with the traditional tree-length (TL) and full-tree (FT) systems. In many specific conditions, the CTL system is cost competitive with tree-length harvesting. However, some of the advantages have not been sufficiently defined for specific conditions, particularly related to cross-country ability and ecology.

Mechanized CTL harvesting in thinning and clear felling and extraction are potentially damaging to harvesting sites, as the operations are conducted under all weather conditions involving predominantly heavy machinery (Zeleke et al. 2007). Fig. 1 illustrates the extreme condition of rut formation on the forest soil that was made by multiple passages of a loaded forwarder in Russia. Extreme machine sinkage has a direct influence on the productivity, fuel consumption, and cost of harvesting operations, and leads to site disturbance and soil damage. This is especially true in areas with soft soils in spring and autumn, where some options are used to improve the operational capability of the existing CTL system, such as »bogie track« and »slash reinforcement« (Fig. 2).

A forwarder equipped with a bogie track has a low average ground pressure on soil in comparison with a conventional wheel with a tire. Consequently,

Fig. 1 Typical rut on silt loam soil caused by forwarder passes

Slika 1. *Karakterističan kolotrag forvardera na pjeskovitoj ilovači*

the external motion resistance on soft terrain is much lower, and drive speed and efficiency are more improved. In addition, sinkage and soil compaction are reduced and damage to the ecology (terrain) is minimized (Batelaan 1998).

CTL harvesters spread limbs and tops in their path as they process stems. Trails covered with slash avoided rut formation, showed lower decreases in porosity, and saturated hydraulic conductivity (Eliason and Wästerlund 2007, McMahon and Evanson 1994, Jakobsen and Moore 1981). The effect of a residue layer in reducing soil compaction was considered positive, although a statistically significant influence was not found (McDonald and Seixas 1997).

Fig. 2 Bogie track and slash reinforcement

Slika 2. *Polugusjenica i zastor granjevine na tlu*

Table 1 Description of harvesting sites and machinery

Tablica 1. *Opis mjesta istraživanja i strojeva*

Region *Pokrajina*	Cut block *Sječina*	Tree species *Vrste drveća*	Stock *Zaliha*	Stem volume *Obujam stabla*	Forwarder *Forvarder*	Loading, per test pass *Opterećenje po testnom prolasku*
	ha	%	m^3/ha	m^3		
Karelia	16.5	Pine – *Bor*, 30 Spruce – *Smreka*, 30 Birch and Aspen – *Breza i trepetljika*, 60	162	0.215	6WD Ponsse ELK Carrying capacity – *Nosivost*: 13 t Tyres – *Gume*: front – *prednje* 700/55 × 34, back – stražnje 710/45 × 26,5, pressure – *tlak punjenja guma*: 350 kPa Ground clearance – *Klirens vozila*: 0.67 m Tracks – *Polugusjenice*: 700 × 26.5	13 tons (16 m^3 timber) *13 tona* *(16 m^3 drva)*
Tver	21.2	Spruce – *Smreka*, 30 Birch – *Breza*, 20 Aspen – *Trepetljika*, 50	252	0.314	8WD John Deere 1410 Carrying capacity – *Nosivost*: 14 t Tyres – *Gume*: front and back – prednje i stražnje 710/45 × 26,5, pressure – *tlak punjenja guma*: 350 kPa Ground clearance – *Klirens vozila*: 0.605 m Tracks – *Polugusjenice*: »Olofsfors«700 × 26.5	13 tons (16 m^3 timber) *13 tona* *(16 m^3 drva)*

Table 2 Description of treatments

Tablica 2. *Opis inačica pokusa*

No. *Oznaka*	Region *Pokrajina*	Ground contact device *Vozni sustav stroja*	Surface *Površina*	Moisture content, % *Sadržaj vlage, %*	No. of test plots *Broj pokusnih ploha*	Number of samples *Veličina uzorka*	
						Rut depth *Dubina kolotraga*	Soil – *Tlo*
KW93	Karelia	Conventional wheel with tire *Kotač s gumom*	Forest soil *Šumsko tlo*	93	11	20	44
KT93	Karelia	Bogie track *Polugusjenica*	Forest soil *Šumsko tlo*	93	11	20	44
KW80	Karelia	Conventional wheel with tire *Kotač s gumom*	Forest soil *Šumsko tlo*	80	11	20	44
KT80	Karelia	Bogie track *Polugusjenica*	Forest soil *Šumsko tlo*	80	11	20	44
TW88	Tver	Conventional wheel with tire *Kotač s gumom*	Slash mat* Zastor granja*	88	11	-	44
TT88	Tver	Bogie track *Polugusjenica*	Slash mat* Zastor granja*	88	11	-	44

*14.2–15.6 kg/m^3

Several studies (Bygdén et al. 2003, Šušnjar et al. 2006, Sakai et al. 2008, Syunev et al. 2009) have shown an advantage when covering extraction trails with slash or using a bogie track. However, the benefits have not been clearly defined for specific conditions. This research was intended to investigate how a bogie track and slash reinforcement influence the sinkage and compaction of prevalent silt loam soil, and how these effects interact with forwarder travel and moisture content.

2. Methods and data – *Metode i podaci*

The first study experiment on the effect of a bogie track was carried out at a cutting area near the town of Medvezhegorsk in the Republic of Karelia, Russia. The tests were conducted in late spring 2009. The forwarder used in the study was a Ponsse ELK.The second study experiment on the effect of slash was carried out at a cutting area near the town of Vyshny Volochek in the Tver region, Russia. The tests were conducted in early autumn 2009. The forwarder used in the study was a John Deere 1410.

Descriptions of the cutting areas and machinery are shown in Table 1. Soils in the test areas were silt loams, and moisture contents were 80%, 88%, and 93%. The forwarders were equipped with 710/45 × 26.5 tires inflated to 350 kPa, and passed over the plots in one direction at about 4 km/h. One pass was defined as one trip of the loaded machine with a loaded weight of 13 tons of timber.

Six linear test plots (30 m × 4 m) were installed in cutting areas. On each plot, measurement points were set as follows: left rail, right rail, and cutting strips (monitoring of natural properties). The rut depth was measured in both right and left rails and the average value of the trail depth was calculated. To determine the soil compaction, the organic layer was removed from each measurement point and soil samples were taken using a soil hammer. Soil samples were taken at measurement points according to a standardized methodology (GOST 12071–84) from the surface layer of 0–5 cm in the central zone of the skid trails. The soil samples were delivered to the soil laboratory in airtight packaging and weighed with electronic balances with a resolution of 0.01 g. The bulk density of the soil samples was also determined.

The following six treatments (combination of ground contact devices, surfaces, moisture contents *W*; Table 2) with one to ten passes were assigned to each of the plots within each block:

forest soil, conventional wheel with tire, W = 93%, (KW93)

forest soil, bogie conventional track 700×26.5, W = 93%, (KT93)

forest soil, conventional wheel with tire, W = 80%, (KW80)

forest soil, bogie track, W = 80%, (KT80)

15 kg/m^2 slash layer, conventional wheel with tire, W = 88%, (TW88), and

15 kg/m^2 slash layer, bogie combination track 700×26.5, W = 88%, (TT88).

The choice of the number of passes equal to 10 was made based on a previous study that indicated that the most compaction occurs within the first trips (Syunev et al. 2009).

The number of rut depth and soil samples for each treatment was 20 and 44, respectively. The choice of number of soil samples after each pass for each treatment, equal to 4, was made based on the prior study experiment and calculation as follows (Redkin 1988):

$$N \geq \frac{\sigma^2 \; z^2}{\rho^2 p^2} \quad (1)$$

Where:

ρ mean of bulk density (ρ = 1.13 g/cm^3),

σ quadratic deviation of bulk density (σ = 0.047 g/cm^3),

z certainty index (z = 1.96 for a 95% confidence interval),

p measurement accuracy (p = 0.05 for a 95% confidence interval).

The slash was collected from a mixed stand in Tver region (see Table 1, Fig. 3) that was clear-cut by a harvester. Ten linear test plots (1–1.5 m) were installed along the skid trails. On each plot, the slash was gathered and weighed with spring balances with a resolution of 0.1 kg. The weight of heavy pieces (over 10 kg) was calculated using log diameter, length and tree species density. Slash densities for these conditions were about 15 kg/m^2, slash mat thickness varied from 15 to 20 cm, comparable to the values in other studies (for example, Galaktionov et al. 2009). There was a large variation in limb size including 18% of large limbs (more than 10 cm diameter) and 15% of tops remaining after processing (Fig. 3).

Soil compaction was analyzed using changes in bulk density following traffic. The soil samples for bulk density were collected with a soil hammer with a 4 cm diameter and 4 cm length rings. Oven-dry weight (12 hours at 105 °C) was used to express bulk density as weight/unit volume (g/cm^3) and moisture content.

Four samples were taken for bulk density at each of 11 depths in the soil profile (0–5 cm) for a total of 44 from each plot. This sampling regime was applied to both pre-treatments (a total of 20 samples per plot). In addition to changes in soil physical properties, soil disturbance was quantified using measures of rut depth at the midpoint of each plot. All samples were collected after passes, with undisturbed samples collected from the rut centre line.

Soil type was classified according to the Russian soil-classification standard (GOST 25100-95) based on the plasticity index and the relative proportions of the various soil separates as described by the classes of soil texture. The name of the textural soil class was adapted to the USDA system using the Glossary of Terms in Soil Science (1976).

Fig. 3 Brush mat, before and after consolidation

Slika 3. *Zastor granjevine prije i nakon prolaska vozila*

The data were statistically processed using statistical and regression analyses with SPSS 15.0 for Windows.

3. Results – *Rezultati*

3.1 Impact of a bogie track – *Utjecaj polugusjenica*

The average soil water contents at the study time were 93% for the wet plots and 80% for the moist plots, without slash reinforcement. Pre- and post-treatment rut depth and bulk density means are shown in Table 3 (KW93, KT93, KW80, and KT80).

In the case of a wheel with a tire on wet soil (KW93), the initial soil bulk density value was 1.06 g/cm^3. The post-treatment bulk density increased slightly up to 1.15–1.17 g/cm^3 during the first 5 passes. It was slightly lower by the 6th and 7th passes at 1.11 g/cm^3, and grew again and stabilized by the 9th and 10th passes at 1.14 g/cm^3. The rut depth increased rapidly up to 0.71 m, particularly during the first 5 passes. The forwarder clearance (0.67 m) was exceeded on the 9th pass.

In the case of a bogie track on wet soil (KT93) the initial soil bulk density was 1.03 g/cm^3. The post-treatment bulk density increased slightly up to 1.17 g/cm^3 within the first 6 passes. Then it decreased slightly by the 7th to 10th passes and stabilized at 1.13 g/cm^3. The rut depth increased evenly up to 0.48 m, particularly during the first 3 passes. The forwarder clearance was not exceeded.

In the case of a wheel with a tire on moist soil (KW80) the initial soil bulk density was 1.06 g/cm^3. The post-treatment bulk density increased up to 1.33 g/cm^3 within the first 4 passes. Then it decreased slightly by the 5th to 7th passes at 1.29 g/cm^3, decreased again, and stabilized by the 8th to 10th passes at 1.24 g/cm^3. The rut depth increased rapidly up to 0.40 m, particularly during the first 7 passes. The forwarder clearance was not exceeded.

In the case of a bogie track on moist soil (KT80) the initial soil bulk density was 1.05 g/cm^3. The post-treatment bulk density increased slightly up to 1.33 g/cm^3 within the first 6 passes. Then it decreased slightly by the 7th to 10th passes and stabilized at 1.30 g/cm^3. The rut depth increased evenly up to 0.22 m. The forwarder clearance was not exceeded.

3.2 Impact of a slash layer – *Utjecaj zastora granjevine*

The average soil water content during the study time was 88%, and the slash had a density of 15 kg/m^2. Pre- and post-treatment bulk density means are shown in Table 3 (TW88 and TT88). The initial soil bulk density was 1.06 g/cm^3.

Table 3 Rut depths and bulk density changes by treatments and passes
Tablica 3. *Promjene dubine kolotraga i prirodne gustoće tla po inačicama pokusa i broju prolazaka*

	Number of pass – *Broj prolazaka*										
	0	1	2	3	4	5	6	7	8	9	10
KW93											
Bulk density – *Prirodna gustoća tla*, g/cm^3	1.06	1.10	1.13	1.17	1.15	1.15	1.13	1.11	1.11	1.14	1.14
Change, % of initial density *Promjena, % od početne gustoće tla*		3.4	6.6	9.2	8.2	7.8	6.0	4.8	4.4	7.2	6.8
Rut depth – *Dubina kolotraga*, m		0.16	0.26	0.34	0.41	0.47	0.53	0.58	0.62	0.67	0.71
Change, % of forwarder clearance *Promjena, % od klirensa forvardera*		24	39	51	61	70	79	87	93	100	106
KT93											
Bulk density – *Prirodna gustoća tla*, g/cm^3	1.03	1.07	1.12	1.15	1.17	1.17	1.17	1.16	1.15	1.13	1.13
Change, % of initial density *Promjena, % od početne gustoće tla*		3.8	7.6	10.6	11.5	11.8	11.4	10.8	10.5	8.5	8.7
Rut depth – *Dubina kolotraga*, m		0.09	0.14	0.22	0.23	0.28	0.32	0.36	0.39	0.44	0.48
Change, % of forwarder clearance *Promjena, % od klirensa forvardera*		13	21	33	34	42	48	54	58	66	72
KW80											
Bulk density – *Prirodna gustoća tla*, g/cm^3	1.06	1.14	1.21	1.27	1.33	1.27	1.29	1.27	1.22	1.24	1.24
Change, % of initial density *Promjena, % od početne gustoće tla*		6.8	12.8	16.8	20.6	16.5	17.7	16.8	13.0	14.7	14.8
Rut depth – *Dubina kolotraga*, m		0.08	0.11	0.15	0.21	0.24	0.27	0.33	0.34	0.35	0.40
Change, % of forwarder clearance *Promjena, % od klirensa forvardera*		12	16	22	31	36	40	49	51	52	60
KT80											
Bulk density – *Prirodna gustoća tla*, g/cm^3	1.05	1.10	1.16	1.23	1.26	1.29	1.33	1.32	1.27	1.31	1.30
Change, % of initial density *Promjena, % od početne gustoće tla*		4.4	9.2	14.7	16.1	18.4	20.6	20.1	17.4	19.5	19.0
Rut depth – *Dubina kolotraga*, m		0.05	0.08	0.1	0.13	0.13	0.15	0.16	0.18	0.20	0.22
Change, % of forwarder clearance *Promjena, % od klirensa forvardera*		12	16	22	31	36	40	49	51	52	60
TW88											
Bulk density – *Prirodna gustoća tla*, g/cm^3	1.06	1.07	1.08	1.08	1.09	1.10	1.11	1.11	1.11	1.11	1.12
Change, % of initial density *Promjena, % od početne gustoće tla*		0.5	1.6	2.0	2.2	3.4	4.1	4.3	4.5	4.5	5.2
TT88											
Bulk density – *Prirodna gustoća tla*, g/cm^3	1.06	1.08	1.08	1.08	1.09	1.09	1.09	1.10	1.10	1.10	1.11
Change, % of initial density *Promjena, % od početne gustoće tla*		1.4	1.8	1.9	2.3	2.2	2.6	3.4	3.7	3.5	4.4

In the case of a conventional wheel (TW88) the post-treatment bulk density increased slightly up to 1.10 g/cm^3 within the first 5 passes. Then it stabilized by the 6th to 10th passes at 1.11 g/cm^3. Ruts were not detected (less than 0.05 m).

In the case of a bogie track (TT88) the post-treatment bulk density increased slightly up to 1.08 g/cm^3 within the first pass. It then stabilized at 1.10–1.11 g/cm^3. Ruts were not detected (less than 0.05 m).

Bulk density and rut depth trend curves based on the obtained data were constructed using a Cubic regression model with *R*-square values of 0.99 for depths and 0.80–0.99 for density:

$$D=b_0+b_1\cdot v+b_2\cdot v^2+b_3\cdot v^3 \quad (2)$$

Where:

D rut depth (m) or bulk density (g/cm^3),

v cumulative volume of extracted timber (m^3),

b_0, b_1, b_2, b_3 coefficients of equation.

The coefficients of the Cubic model as a function of treatment conditions (moisture contents, tracks, slash) are presented in Table 4. Fig. 4 shows the relationship between extracted timber volume and rut depth. Fig. 5 shows the relationship between extracted timber volume and bulk density.

3.3 Soil classification – *Razredba tla*

The results of soil classification are presented in Table 5. The difference between initial mass and total mass of samples did not exceed 0.05 g (less than 0.05%). The relative proportions of the various soil separates in the studied soils corresponded to the silt loam class.

4. Discussion and conclusions – *Rasprava i zaključci*

Regarding soil compaction, the CTL system met the ecological requirements for this type of forest soil (1.4 g/cm^3) within the bounds of the experimental design. However, an increase in bulk density was found in all treatments at the silt loam soil surface (0

Table 4 Coefficients of the Cubic model as a function of treatment conditions

Tablica 4. *Koeficijenti modela procjene dubine kolotraga i gustoće tla*

No. *Oznaka*	Bulk density – *Prirodna gustoća tla*				Rut depth – *Dubina kolotraga*			
	b_0	b_1	b_2	b_3	b_0	b_1	b_2	b_3
KW93	1.054	0.004	–5.53E-05	2.02E-07	0.052	0.007	–3.22E-05	7.45E-08
KT93	1.023	0.004	–3.49E-05	8.30E-08	0.020	0.005	–2.457E-05	8.16E-08
KW80	1.046	0.008	–8.20E-05	2.44E-07	0.033	0.003	–2.96E-06	3.088E-08
KT80	1.038	0.005	–2.80E-05	3.65E-08	0.012	0.003	–2.01E-05	7.07E-08
TW88	1.060	0.001	–7.97E-07	-3.32E-09				
TT88	1.064	0.001	–6.15E-06	2.28E-08				

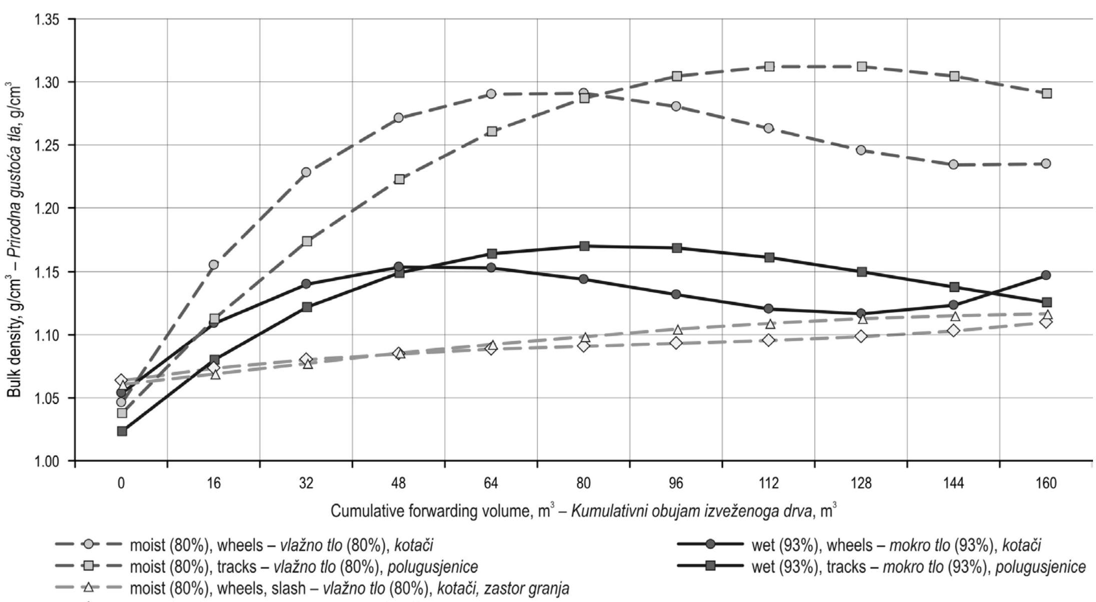

Fig. 4 Relationship between extracted timber volume and bulk density

Slika 4. *Ovisnost obujma izveženoga drva i prirodne gustoće tla*

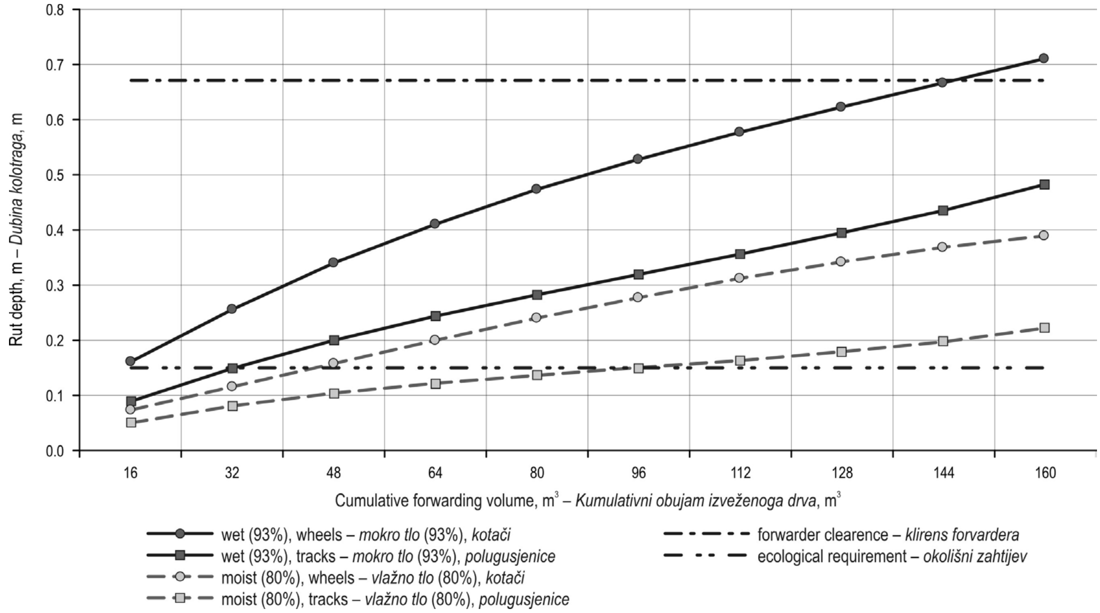

Fig. 5 Relationship between extracted timber volume and rut depth

Slika 5. *Ovisnost obujma izveženoga drva i dubine kolotraga*

Table 5 Distribution of samples by size of soil particles

Tablica 5. *Granulometrijski sastav tla po inačicama pokusa*

	Soil particles percentage – *Postotni udio čestica tla*						
	Prior	Treatments – *Inačice pokusa*					
	Prije	KW93	KT93	KW93	KT93	TW88	TT88
Sand particles – *Čestice pijeska*	27	31	32	35	35	30	29
Silt particles – *Čestice praha*	55	53	51	50	50	52	53
Clay particles – *Čestice gline*	18	16	17	15	15	18	18
Plasticity index – *Indeks plastičnosti*	11.0	10.3	10.6	9.7	9.5	11.1	11.2
Grain size distribution – *Granulometrijski sastav*	Silt loam – *Pjeskovita ilovača*						

to 5 cm depth). The magnitude of the increase was a function of the number of passes, the slash/track presence, and the moisture content. In comparison with conventional wheel treatments, bogie track treatments showed that compaction of wet and moist silt loam held irregularly. The formation of a compacted zone under the traction element, helped by reinforcement of forest soil roots, took place in the first phase. With the increasing number of passes the compacted zone deepened and partly collapsed, and there was a lateral bulging of the soil. Then there was a slight increase in density, due to the formation of secondary hardened zones. The results for slash reinforcement treatments indicated that a layer of slash mitigated the effect of a single forwarder pass and subsequent passes. The bulk density did not change considerably. The increased bulk density for the forest soils was nearly 10% of that of the slash covered soils. Also, the present of the combination »slash + track« made no apparent difference within the bounds of the experimental design.

Regarding sinkage, the CTL system with a conventional wheel did not meet the ecological requirements for thinning (rut depth should be less than 0.15 m). Moreover, rut depth reached the forwarder clearance of the machine (0.67 m) on wet soil. The results of bogie track treatments showed that the rut depth did not meet the ecological requirements for thinning (0.15 m) particularly on wet soil, but was within the forwarder clearance of the machine. In the slash treatments the rut depth changed only slightly.

All mechanized harvesting systems (TL, FT, CTL) applied in Russia cause different kinds of negative environmental impacts. When applied on sandy or sandy loam soils, all mechanized systems demonstrated almost the same impacts on the soil (Syunev et al. 2009). However the proportion of sandy soils is small in Russian forests in comparison with loams and clays. On loams and clays, the TL and FT systems, unlike the CTL system, resulted in significant soil compaction, but at the same time formed almost no track. Over 50% of the harvesting sites in Russia are on wet and soft soil (Ananyev et al. 2005). Therefore, the application of the CTL system has to be improved in order to reduce rut formation in most common soils. Hence, the associated CTL machine ground contact devices and slash layer must be suitably adapted for specific harvesting sites, based on terrain classification criteria. The adaptation requires a further study of the effects of the ground contact device (tire or track) and size of slash layer, the induced ground contact pressure, and the physical characteristics of the slash layer that are affected during soil deformation, which negatively influence the CTL system cross-country ability and environmental impact.

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Sažetak

Utjecaj polugusjenica i zastora granjevine na dubinu kolotraga i zbijanje tla pri izvoženju drva forvarderom na tlu ograničene nosivosti

Istraživanje je provedeno u proljeće i jesen na dvama lokalitetima u Rusiji radi utvrđivanja utjecaja polugusjenica na bogi kotačima i zastora granjevine pri višekratnim prolascima forvardera na deformaciju i zbijanje pjeskovito-ilovastoga tla. Istraživanje utjecaja polugusjenica na bogi kotačima forvardera Ponsse ELK (sl. 1) na zbijanje tla provedeno je u kasno proljeće 2009. godine na području Karelije. Iduća su ispitivanja zbijanja tla pri prolasku forvardera John Deere 1410 uz polaganje granjevine uzduž kolotraga provedena u oblasti Tver u jesen iste godine. Opisi sječina i korištenih forvardera dani su u tablici 1 i na slici 2. Tlo je po granulometrijskom sastavu odgovaralo pjeskovitoj ilovači, sa sadržajem vlage 80 %, 88 % i 93 %, a gustoća polagane granjevine na tlo je iznosila 15 kg/m^2*. Na ukupno šest pokusnih ploha vozilo je prolazilo 1 do 10 puta, na svakoj su plohi uzeta 44 uzorka tla (tablica 2).*

Zbijanje je tla istraživano zbog promjena u gustoći tla i dubini kolotraga nastalim zbog višekratnoga prolaska vozila. Prilikom uzimanja uzoraka tla (valjci promjera 4 cm te duljine 4 cm) gornji (organski) sloj tla je uklonjen te su uzorci tla vađeni s dubine 0 do 5 cm na sredini kolotraga. Hermetički zatvoreni valjci dostavljeni su u laboratorij gdje im je mjerena masa prije i nakon sušenja (na 105 °C) radi izračunavanja vlage, odnosno gustoće tla.

Dubina je kolotraga iskazana kao srednja vrijednost mjerenja lijevoga i desnoga kolotraga voznoga sustava (kotač, polugusjenica) forvardera.

Istraživanje je na području Karelije pokazalo da je prosječna mokrina tla iznosila 93 % kod mokroga tla te 80 % na vlažnom tlu bez postavljanja zastora granjevine na tlo. Promjene dubine kolotraga te gustoće tla zbog višekratnoga prolaska vozila prikazane su u tablici 3 (KW93, KT93, KW80 i KT80).

U slučaju prolaska vozila bez polugusjenica na mokrom tlu (KW93) početna je gustoća tla iznosila 1,06 g/cm^3*, a nakon prvih 5 prolazaka forvardera porasla je od 1,15 do 1,17 g/cm*^{3}*. Daljim prolascima forvardera (6. i 7. prolazak) uočen je pad gustoće tla na vrijednost od 1,11 g/cm*^{3}*, a dodatnim prolascima gustoća je tla neznatno ponovno rasla te se ujednačila na 1,11–1,14 g/cm*^{3}*. Dubina se kolotraga naglo povećavala tijekom prvih 5 prolazaka forvardera, a nadišla je klirens forvardera (0,67 m) nakon 9. prolaska vozila.*

U slučaju prolaska vozila s polugusjenicama na mokrom tlu (KT93) početna je gustoća tla bila 1,03 g/cm^3*, dok je gustoća nakon 6 prolazaka vozila porasla do 1,17 g/cm*^{3}*. Zatim je gustoća tla bila nešto manja pri 7. do 10. prolasku vozila te se ujednačila na vrijednosti od 1,13 g/cm*^{3}*. Dubina se kolotraga ravnomjerno povećavala do 0,48 m, osobito tijekom prva 3 prolaska vozila te dubina kolotraga jednaka klirensu forvadera nije dostignuta.*

U slučaju prolaska vozila bez polugusjenica na vlažnom tlu (KW80) početna je gustoća tla bila 1,06 g/cm^3*, dok je gustoća nakon 4 prolaska vozila porasla do 1,33 g/cm*^{3}*. Zatim je gustoća tla bila nešto manja od 5. do 7. prolaska vozila (1,29 g/cm*^{3}*) te je njezina vrijednost ujednačena i opet smanjena od 8. do 10. prolaska vozila na 1,24 g/cm*^{3}*. Dubina se kolotraga naglo povećavala do 0,40 m osobito tijekom prvih 7 prolazaka vozila, dok dubina kolotraga jednaka klirensu forvadera nije dostignuta.*

U slučaju prolaska vozila s polugusjenicama na vlažnom tlu (KT80) početna je gustoća tla bila 1,05 g/cm^3*, dok je gustoća nakon 6. prolaska vozila porasla do 1,33 g/cm*^{3}*. Zatim je gustoća tla bila nešto manja pri 7. do 10. prolaska vozila te se ujednačila na vrijednosti od 1,30 g/cm*^{3}*. Dubina se kolotraga ravnomjerno povećavala do 0,22 m te dubina kolotraga jednaka klirensu forvadera nije dostignuta.*

Istraživanje je u oblasti Tver pokazalo da je prosječna količina vode u tlu iznosila 88 % te da je gustoća polagane granjevine bila 15 kg/m^2 *(sl. 3). Gustoća je tla prije i poslije prolaska vozila prikazana u tablici 3 (TW88 i TT88) od početne 1,06 g/cm*^{3}*.*

U slučaju vozila bez polugusjenica na kotačima (TW88) gustoća je tla nakon 5 prolazaka vozila neznatno porasla do 1,10 g/cm^3*, dok je od 6. do 10. prolaska vrijednost gustoće tla ujednačena na 1,11 g/cm*^{3}*. Pojavnost kolotraga nije zabilježena jer je njihova dubina bila manja od 0,05 m.*

U slučaju vozila s polugusjenicama na kotačima (TT88) gustoća je tla nakon 1. prolaska vozila neznatno porasla do 1,08 g/cm^3*, zatim je vrijednost gustoće tla porasla od 1,10 do 1,11 g/cm*^{3}*. Pojavnost kolotraga nije zabilježena jer je njihova dubina bila manja od 0,05 m.*

Uz pomoć kubnoga regresijskoga modela dobiveni su koeficijenti determinacije R^2 od 0,99 za dubinu kolotraga i 0,80–0,99 za gustoću tla. Koeficijenti u ovisnosti o uvjetima na terenu (sadržaj vlage u tlu, kotači bez polugusjenica ili s njima, granjevina na tlu) prikazani su u tablici 4. Slika 3 prikazuje odnos između privučenoga drvnoga obujma i dubine kolotraga, a slika 4 prikazuje odnos između privučenoga drvnoga obujma i gustoće tla.

Vrsta je tla određena prema ruskom standardu klasifikacije tla koji se temelji na indeksu plastičnosti i relativnim odnosima frakcija u tlu, što u krajnosti određuje teksturu tla. Naziv razreda tla prilagođen je sustavu USDA (United States Department of Agriculture). Rezultati su klasifikacije tla prikazani u tablici 5.

Rezultati promjene gustoće tla (zbijanje tla) pokazali su da je sortimentna metoda pridobivanja drva sustavom harvester – forvarder okolišno prihvatljiva za pjeskovitu ilovaču (gustoća tla 1,4 g/cm^3) unutar granica oblikovanoga pokusa. Međutim, gustoća se tla povećala na svim plohama istraživanja na dubini tla od 0 do 5 cm. Povećanje je gustoće tla ovisilo o broju prolazaka vozila, prisutnosti zastora granjevine na tlu i sadržaju vlage u tlu. Pri korištenju polugusjenica na forvarderu zbijanje je vlažnoga i mokroga tla bilo nepravilno. S povećanjem broja prolazaka vozila zona se zbijenoga tla produbljivala, dok se postavljanjem granjevine na tlu ne prelaze granice postavljenoga pokusa.

Postavivši okolišno prihvatljivu granicu dubine kolotraga od 0,15 m, uporaba forvardera s polugusjenicama na kotačima na tlima povećane vlažnosti (smanjene nosivosti tla) ekološki je neodrživa. Štoviše, dubina je kolotraga dosegla visinu klirensa vozila (0,67 m) na mokrom tlu. Pri korištenju polugusjenica dubina je kolotraga na mokrom tlu, također, bila veća od 0,15 m te je samim time i ekološki nepodobna, ali ipak nije premašila visinu klirensa vozila. Polaganjem granjevine na tlo kolotrag nije zabilježen.

Svi strojni sustavi pridobivanja drva u Rusiji uzrokuju različite vrste negativnih utjecaja na okoliš. Kada se primjenjuju na pjeskovitim ili ilovasto-pjeskovitim tlima, svi su sustavi pridobivanja drva pokazali gotovo isti utjecaj na tlo. Međutim, udio pjeskovitih tala u ruskim šumama nije značajan. Na glinovitim tlima deblovna i stablovna metoda, za razliku od sortimentne metode pridobivanja drva, uzrokuju značajno veća zbijanja tla. Preko 50 % sječina u Rusiji se nalazi na mokrim i mekim tlima. Stoga se primjena sortimentne metode mora poboljšati kako bi se smanjila dubina kolotraga na tlu te se, ovisno o terenskim uvjetima, treba odrediti korištenje ili nekorištenje polugusjenica na kotačima vozila (smanjivanje dodirnih tlakova) te debljina polagane granjevine na tlo, a sve radi zaštite tla od negativnoga utjecaja vozila pri privlačenju drva.

Ključne riječi: sortimentna metoda, forvarder, dubina kolotraga, prirodna gustoća tla, zastor grana, polugusjenica, Rusija

Authors' address – *Adresa autorâ:*

Yuri Gerasimov, PhD.
e-mail: yuri.gerasimov@metla.fi
Finnish Forest Research Institute
Joensuu Research Centre
Yliopistokatu 6
Box 68
FIN–80101 Joensuu
FINLAND

Vasily Katarov, PhD.
e-mail: vkatarov@psu.karelia.ru
Petrozavodsk State University
Forest Engineering Faculty
A. Nevsky av., 58
185030, Petrozavodsk
Republic of Karelia
RUSSIA

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