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Pressure Control Systems for Tyre Preservation in Forestry Machinery and Forest Soils

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Abstract: Most forestry machinery today has a wheel-driven engine, and its tyre pressure has a significant impact on the compaction and degradation of the forest soil, causing environmental damages. Not only the durability of the tyres but also the driving characteristics and productivity of wheeled forest machines depend on the correct choice of pressure and competent operation. This work aims to analyse modern tyre pressure control technologies to develop an automated tyre pressure control system for wheeled forest machinery and lower the environmental impact. A new tyre pressure control system in forest machines was developed using a PressurePro solution, which contributes to a lower negative influence on the soil and reduces expenses for diagnostics and fuel. The study results of the tyre-to-ground contact pressure show that the installation of an automatic tyre pressure control system leads to its decrease by 20%. However, as the number of passes increases, the pressure might slightly increase. The study of humus content and soil compaction demonstrates that reduced tyre pressure and its automatic control contribute to a minimal reduction in humus content and soil compaction over time. Installation of the tyre pressure and temperature control system on forestry machines allows the system to be implemented quickly due to the simplicity of installation and operation.

Key words: Tyre pressure control, pressure control systems, tyre inflation systems, soil of the logging site, ecology.

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Introduction

Reducing compaction and deformation of forest soils is a major challenge for modern wheeled forest machinery (Marusiak and Neruda, 2018). Particular attention is paid to the problems related to the constant transportation of wood from the forest site to the loading zone.

The vast majority of modern forest machinery has a wheel-driven engine, and hence, the tyre pressure has a significant impact on the soils of forest sites. The over inflation of the tyre facilitates the process of soil destruction and pre-consolidation. Based on photogrammetric profile measurements, soil disturbance is influenced by tyre pressure and the number of passages. For example, an increase in tyre pressure from 150 to 300 kPa increases the rutting volume on the runway from 5.74 to 8.48 m^3 after passages of 60 forwarders (Marra et al., 2018).

Depending on the stress level or moisture content of the soil, the passage of the forest machinery incites plastic deformation and irreversible soil degradation. The main problems related to the use of wheeled forestry machinery are a disturbance of load-bearing capacity, homogenisation of soil structure, and loss of passability. The use of wide forest belts or special tracked vehicles reduces the impact on soil structure and, at the same time, activates stronger lateral forces, which also negatively affect soil properties (Riggert et al., 2019).

Because of some peculiar aspects involved in the forest operations, the tyres of the machinery have a quite specific design (Figure 1).

Undoubtedly, at a rather high initial cost, each element of a forwarder, harvester, and skidder must meet the highest requirements of reliability, durability, safety, as well as be consistent with strict environmental standards (Cadei et al., 2020; Grigorev et al., 2020). The same high demands apply to tyres as to equipment. The tyres must ensure high driving qualities of the machinery (high capacity to cross the country, even in difficult forests, swampy or icy soils), resist damage, resist heavy loads (Lee and Taheri, 2017). Not only their durability, but also the operating characteristics and productivity of forest machinery depend on the right choice and competent use of tyres for harvesters, forwarders, or skidders.

The operation of forest machinery at the minimum tyre pressure allows better traction of the machine and greater comfort for the operator in service. But then again, it reduces the stability of the machine, increases fuel consumption, causes premature tyre wear, and increases the risk of tyre damage. At the same time, the operation of forest machinery at maximum tyre pressure enables higher stability of the machine and a more efficient joint operation of tyre treads and tracks. However, this results in reduced traction at similar engine power, which reduces the operator's comfort during work (Janulevičius and Damanauskas, 2015).

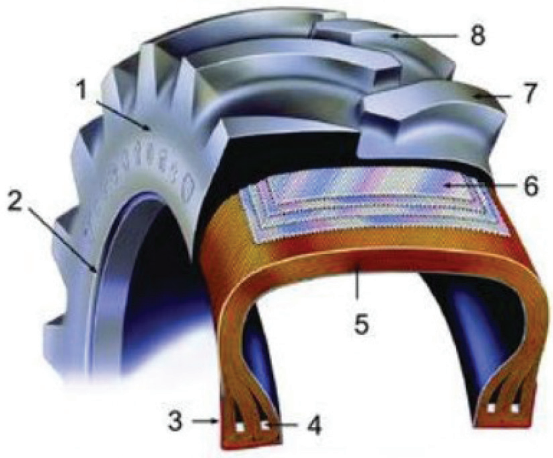

Figure 1: Design elements of FIRESTONE 30.5L-32 construction (Firestone, 2021): (1) reinforced sidewall of special rubber for protection against punctures and cuts; (2) reinforced bead perch protection; (3) abrasion-resistant base ring protection; (4) double base ring; (5) high-strength carcass; (6) steel cord layers for carcass protection against cuts and penetrations; (7) tread blocks positioned at an optimum angle for self-cleaning while maintaining effective tractive effort; (8) tread layer of special rubber with high resistance to abrasion, impact, cuts, and punctures.

Research by Bridgestone (2021) proves that there is a significant effect of failure to comply with the manufacturer's recommended maximum and minimum internal tyre pressures on tyre durability (Table 1).

Table 1: Operation of forestry equipment at the minimum and maximum tyre pressures

Under the minimum allowed		*Above the maximum allowed*	
Pressure	*Service life, years*	*Pressure*	*Service life, years*
Recommended	10	Recommended	10
Below normal by 10%	9	Above normal by 10%	9
Below normal by 20%	7.5	Above normal by 20%	7.5
Below normal by 30%	5	Above normal by 30%	5

The main purpose of chains and tracks is the protection of tyres, antislip, good adhesion of the wheels, and an increase of the machine performance; particularly, in difficult conditions (Argyroudis et al., 2019).

However, the sides of the tyre tread will gradually wear out and poorly selected or incorrectly installed chains or tracks can seriously damage the tyre.

In the installation of tracks and chains, it is necessary to:

- Adhere to manufacturer's recommendations;
- Pay attention to the special marking indicating the possibility or inability to use the tracks;
- Make sure the tracks match the tyres when installing: the distance between the side support of the track and the outside of the tyre should be about 15 mm;
- Ensure the correct track tension for efficient operation; the acceptable track sag between the wheels should not exceed more than 50 mm.

While performing the work, the internal pressure in the tyres must be carefully monitored. They should be well inflated, strictly based on the recommended value for its operation with tracks.

Another important aspect of research is to investigate the negative impact of forestry equipment on the ecology of land cover. This area of interest is associated with the period in which active logging operations involving heavy machinery were used for the first time. To date, at least in the Commonwealth of Independent States (CIS) and developing countries, most forestry work is still carried out with crawlers and wheel machines. These machines generally do not meet increasing environmental standards. Therefore, it is necessary not only to develop new models of machines but also to improve the existing ones to increase their compatibility with the natural environment (Ogrin et al., 2020; Safonov et al., 2020). First and foremost, the negative impact of forestry machinery is reflected on soil properties. They are as follows: soil cover compacts, its hardness increases, the porosity decreases, and soil mineralization process intensifies. Micro relief changes are manifested by rut formation (Zaimes et al., 2020).

Soil compaction results in changes in soil particles compared to one another, which is also accompanied by a reduction in volume. The degree of soil compaction is linked to parameters such as the mechanical composition of the soil, the humidity level, the specific pressure and the vibrations created by the machines. Other characteristics include the number of machine passes, the weight of the machines and/or the cargo they carry, and the design features of the undercarriage of the machines involved in logging (Kuvshinov, 2017; Safonov et al., 2019).

However, there is a need to develop a more affordable and effective tyre pressure control system for harvesters, forwarders, and skidders that are actively used in Russian woodworking enterprises. This work aimed to assess the effectiveness of automatic tyre pressure control systems in reducing the negative impact on the physical and chemical composition of soils and lowering operational costs for tyres used in the Russian forestry companies. A new tyre pressure control system for forest machinery has been developed, which allows for a performance increase, timely diagnosis of tyres for troubleshooting, and cost reduction for modernization and maintenance of machinery.

Another task of this work is to investigate changes in forest soil parameters, such as compaction, contact pressure, and humus content under the influence of mechanized logging. This appears relevant since the data obtained on soil compaction justify the need to develop monitoring systems.

Methods Involved in Tyre Pressure Control and Monitoring

Automatic Tyre Pressure Monitoring Systems

Unfortunately, in the practice of national forestry enterprises, it is by no means customary to vary the tyre pressure depending on the driving surface of the machine. However, there should be a difference between the tyre pressures when working on a winter logging site and water-logged soils in summer.

Many tyre-pressure monitoring system providers offer pressure monitoring system kits for heavy duty trucks, including trailers, tractors, etc. For example, PSI ATIS (2021), Doran Manufacturing (2021), Valor TPMS (2021), PressurePro (2021), and Stemco (2021). Based on the data requirement and the cost of a particular technology, automobile and truck fleets can evaluate their benefits and payback periods, which depend on savings vehicle owners will earn by reducing the frequency of breakdowns, increasing tyre life, and improving fuel efficiency. In Russia, the majority of forestry fleets prefer PressurePro system as their tyre-pressure monitoring system provider. This tyre pressure and temperature control system makes it possible to track tyre pressure changes not only at the logging site but also at the site of the office.

The data obtained from this control system can assist in resolving disputes, which often becomes the reasons for a system's early and accidental failure, between operators and forest managers or tyre suppliers. The essential point to remember is that the wrong choice of tyres, for example, according to their ply rating, rubber composition, load-bearing capacity, and some other parameters, will lead to their fast failure without the fault of the operating organisation. This system allows the claims to be submitted to tyre manufacturers (suppliers) to enforce warranty obligations (Goryunov et al., 2019).

The technique used in this system is fairly simple technically. The concept of fitting such a system to a tractor is illustrated in Figure 2.

The design of the sensors is indestructible, waterproof, shock-resistant, vibration-resistant, with an independent power supply, whose service life, which 2-3 years, depends on the operating culture. Some examples of their faultless operation for the duration of 7-8 years explains their advantages over other systems are as follows: when the tyre pressure is in the specified range, the sensor switches to a 'stand-by mode' (5 to 120 minutes) and sometimes when the tyre pressure exceeds the pre-defined threshold, the sensor begins to transmit a signal every 5 seconds so that the operator can see the dynamic of the pressure change. However, even then the operator does not pay attention to the monitor's signal and takes no action to correct the situation, the sensor's power supply will fail sooner, and the entire sensor will have to be replaced since it is indecomposable.

The system feature enables setting a time interval during which the specified percentage of pressure deviation will be monitored.

The system is capable of integrating with major dispatch and surveillance service providers. Therefore, not only the operator but also the dispatcher (mechanic) can receive operational information about the pressure and temperature in each tyre or each tractor.

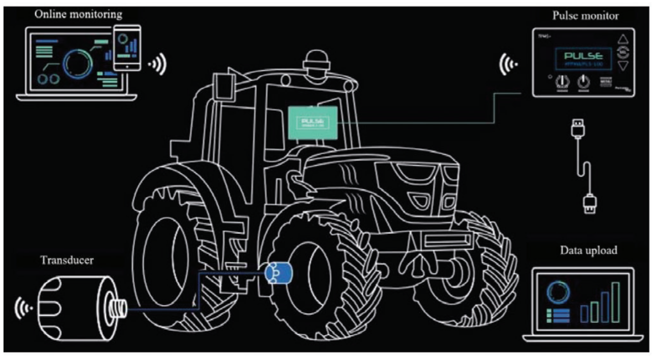

Figure 2: The PressurePro Pulse tyre pressure/temperature monitoring system designed for a tractor.

The sensor programming at a reference pressure is performed directly when the sensor is positioned on the valve. It allows adjustment of the reference pressure on each axle and its position separately on the display. When the wheels reach the operating temperature and there is a corresponding increase in tyre pressure due to heating, the system uses it temporarily as the base pressure (Figure 2).

The system thresholds are manually adjustable, for increasing or decreasing the pressure, from 6%. The system has a 2% measurement error, with stable operation at temperatures ranging from -40°C to 70°C, under 0.5 to 20.5 atmospheres.

Experiments to examine the impact of tractor tyres with and without an autonomous tyre monitoring system were performed on experimental forest plots. A separate track was assigned for each case where the contact area was measured after 5, 10, 15, and 20 tractor runs with and without the system. The tyre contact area was determined by capturing images of the tyre tracks and measuring the runway depth after the certain number of passes. The pictures of the tyre tracks were analysd with the Scion Image software to calculate the contact zone. Afterward, the contact pressure was calculated by recording the wheel pressure on the monitor screen and measuring the contact zone.

Methods for Studying Soil Compaction

To study the extent of soil compaction under the influence of forestry machinery, seven soil transects were laid. As a control, transect laid on a layer of sod-podzolic soil was used, which was located on a nearby forest block and untouched by logging operations. This quarter, as can be seen from the archival records, was not subjected to logging operations using machines. Soil samples were taken from each of the profiles. Their physical and chemical properties, in particular, the density of soil compounds in g/cm^3, were studied under laboratory conditions. Compaction density is considered as the mass of dry undisturbed soil in unit volume. Sampling was performed using special cylinders (drills), which allow taking soil samples without disturbing their structure. The seven transects belonged to forest plots where active logging, in which machinery work had been performed for the past 38 to 49 years. This period was selected to demonstrate that logging operations could have been negatively impacting the environment for at least 38 to 49 years if data are confirmed.

The impact of tyres on changes in vegetation cover in areas where logging equipment passes was estimated by measuring the soil humus content. The content of humus carbon in the soil was determined using a modified method proposed by Kachinskii and Tyurin (1966). The percentage content of humus was calculated from the percentage content of carbon.

Humus content (%) = Carbon content (%) × 1.724 (1)

The work was carried out within the confines of the scientific school “Progress in the wood and forestry industry”.

Results and Discussion

Figure 3 shows the results of tyre pressure calculations for the different numbers of runs.

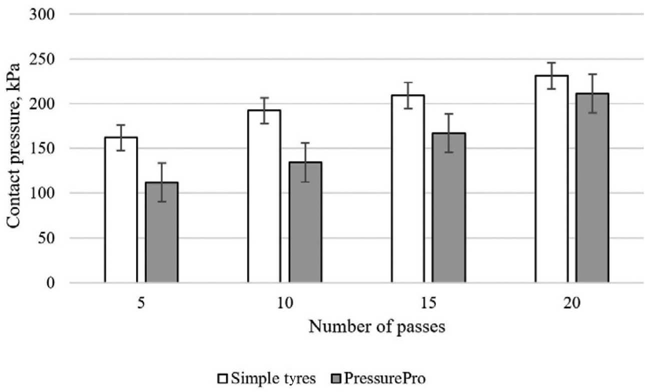

Figure 3: Contact pressure vs. number of passes of forestry machines with conventional tyres and tyres equipped with PressurePro.

As illustrated in the diagram, the contact pressure increases with the greater number of passes. That is probably related to the negative impact of machinery on the soil (compaction) and an increase in the depth of the track, and therefore the amount of wheel skidding and fuel costs. Thus, more machine passages contribute to an increase in contact pressure, which negatively affects the physical properties of the soil and increases the operation cost of the machine. When using an automatic pressure control system, the contact pressure increases, but unlike before, here, the contact pressure is 15% to 20% lower. And results in less sliding, reduction in rutting depth, and less destruction of the topsoil.

A great advantage of the automatic pressure control system for forestry machinery is an option to detect tyre pressure drops when driving with tracks. When a tractor has a flat tyre while moving through the logging site at an angle to the horizon, it becomes difficult for the operator to detect a decrease in tyre diameter when the tyre is punctured. Tyre mileage may be increased by 15-50% when the pressure control system is working properly.

Based on the operating characteristics of forest machines, especially their low operating speeds, such known truck tyre-saving technologies as dynamic wheel balancing and wheel hub alignment sleeves will not be effective. The pressure equalising system in the wheel pairs is not effective either.

The pressure control system with PULSE MINING monitor has a built-in GPS/GLONASS receiver module, a built-in GSM modem, and a built-in WiFi module that quickly transmits data to a unified monitoring system if the logging site is equipped with communication. Besides, the system is integrated with a tablet (smartphone) and has an event log inside the device. In the absence of communication at the logging site, it records data in the monitor and transmits them for pressure compliance analysis, together with the data provided by the basic software of modern logging complexes, such as PONSSE EcoDrive.

Of course, large and medium-sized logging companies need a separate tyre engineer to account for and operate tyres. Such a person may have been trained either in the tyre manufacturing companies or specialised training centers.

Today, autonomous truck manufacturers are integrating new systems that not only automate the tyre pressure monitoring process but also predict breakdowns and malfunctions so that truck owners can avoid unscheduled repairs. One such example is TyreVigil Cloud (2021), an integrated system for tyre monitoring and predictive tyre diagnostics. The system includes four automated response systems that can route or re-route vehicles due to breakdowns and/or tyre issues. This integrated system receives real-time data on tyre pressure, which are then used to predict breakdown anywhere from 5 hours to 30 days prior to a tyre failure and the amount of time safe for the vehicle to be operated using TyreStamp technologies. The integrated system can interact with other systems of the vehicle to assess the quality of the tyre service and efficiently and quickly respond to the needs of tyre repair or replacement. A similar real-time tyre pressure and temperature monitoring system for heavy trucks and forestry vehicles was developed using Valor TPMS (2021). The wireless communication of TPMS allows avoiding potentially dangerous accidents, detecting a malfunction, and estimating the amount of time left before tyre maintenance. In addition, TPMS enables any truck to hook-up any trailer, as it automatically updates the system in real time based on wheel positions and trailer weight. This type of system has convenient and understandable interfaces and can be combined with mobile applications (such as TPMS Doran's Yardcheck 360 system) designed to monitor the system in a smartphone (Doran Manufacturing, 2021).

For estimating the negative impact of forest machinery on the physical and chemical properties of the soil over time, soil samples have been studied at various locations where the machines have been in use for more than 30 years. The results of the humus study of topsoil samples (2-20 cm) are shown in Figure 4.

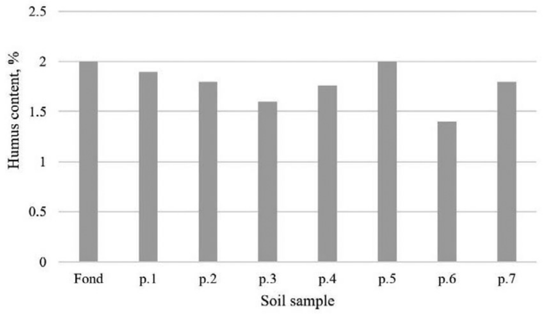

Figure 4: Humus content in soil samples after years of logging equipment passage.

As can be seen, the soil humus content declines after years of wheel machinery movement. The maximum decrease is observed at plot p.6, where the humus content has been observed to decline by almost 30%. This result indicates a reduction of carbon content, which is associated with soil compaction, reduced oxygen, and reduced vegetation cover. Furthermore, increasing the depth of the wheel track contributes to increased leaching of soil nutrients and disturbance of the soil cover structure. The lowest impact was observed in p.5 and p.1 plots where tracked machinery was mainly used which exerted less contact pressure and caused less damage to the soil. As stated above, using an automatic tyre pressure control system reduces the contact pressure between the tyre and the soil. Crawler's machines, an automatic tyre pressure control system, may help to reduce the dynamics of soil humus depletion and provide recovery when the control system is used correctly. Furthermore, the automatic tyre pressure monitoring of wheeled machines ensures rational fuel consumption and tyre wear.

According to the soil density analysis results, such phenomenon has been observed in all surveyed sections (Figure 5).

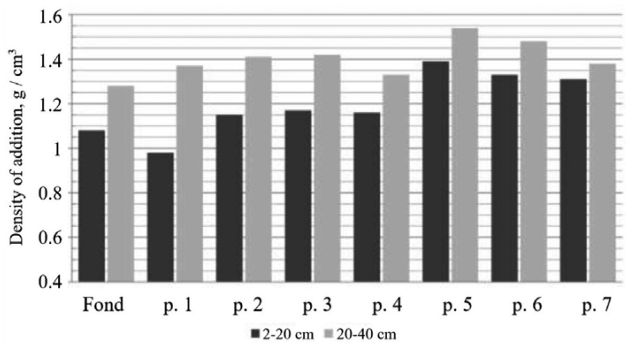

Figure 5: Dynamics of changes in the indicators of soil density under the influence of mechanized logging.

In particular, it was found that the indices of soil compaction in the first horizon exceeded the control by 7–28 % (Figure 5), while the average deviation from the background was 12.8 %. Average values of soil compaction in the second horizon were 4–20 % higher in comparison with control (Figure 5), which also specified the value of average deviation from the background of 10.8 %. The lower horizons did not show noticeable deviations from the norm (control). Thus, even after almost half a century, the soil retains its compaction properties under the influence of forestry equipment.

The degree of soil compaction is mostly influenced by the type of logging operations, as well as the type of machinery itself. The pressure of machines transmits tension into the soil up to a considerable depth.

In this respect, there is a decrease in pores, which modifies the water-air regime of the soil and leads to the degradation of plant root systems. During logging operations, rectilinear movement takes place for only some time, while turning processes exert the maximum negative effect on the soil cover. Particularly, soil rolls are formed during the turning of the tractor beside the compaction (Kotroczó et al., 2020). Depending on the type of tractor and the number of passages, either deepening or stabilising ruts occur. During deepening, soil compaction deformations prevail while during stabilisation, shear deformations prevail (Romanova et al., 2007). Firstly, the passing of the machines will harm the feeding roots of the trees, whose main mass is in the higher horizons. When a machine moves towards each tree during logging, the ecosystem, including the soil, is affected to the maximum (Blokhin et al., 2016). These studies demonstrated that negative impacts can persist on soil in podzolic forests for 50 years. Therefore, the development of tyre pressure monitoring technologies is justified.

Conclusions

Based on the analysis of modern technical solutions, an automatic tyre pressure monitoring system for tyre pressure control in forest machines has been developed. The effect of the number of passes on the tyre-to-soil contact pressure with and without the automatic tyre pressure control system demonstrated a linear increase of the contact pressure in all cases with a higher number of passes. The system reduces contact pressure by as much as 20% compared to conventional tyres. This results in a less negative impact on the soil and a reduction in the operating costs of frequent wheeled machine passages for logging. Reduced contact pressure has been shown to contribute to less soil compaction and minimises the adverse impact on soil humus content. The results obtained can be used as a guide to modernise forest machinery and protect the environment.

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Conflict of interests

The authors declare that they have no conflict of interests.

Data Availability

Data will be available on request.

References

Argyroudis, S.A., Mitoulis, S.A., Winter, M.G. and A.M. Kaynia (2019). Fragility of transport assets exposed to multiple hazards: State-of-the-art review toward infrastructural resilience. *Reliability Engineering & System Safety*, **191:** 106567.

Blokhin, V.N., Kuvshinov, N.M., Rogankov, S.I. and G.V. Orekhova (2016). Development of the construction diagram of the vertical mill rotor to treat tall-stalked cultures. *In*: Modern scientific and practical solutions of the XXI century. Materials of International Scientific-Practical Conference. Science and Education, pp. 88-94.

Bridgestone (2021). Off The Road Tyres. https://www.bridgestone.com/products/speciality_tyres/off_the_road/

Cadei, A., Mologni, O., Röser, D., Cavalli, R. and S. Grigolato (2020). Forwarder productivity in salvage logging operations in difficult terrain. *Forests*, **11(3):** 341.

Doran Manufacturing (2021). Official web site. https://doranmfg.com/

Firestone (2021). Official web site. www.firestone.com

Goryunov, S., Khoreshok, A., Grigoryeva, N., Preis, E. and O. Alitkina (2019). The research of operational temperatures of dump trucks tyres. *In:* E3S Web of Conferences, EDP Sciences, **134:** 01014.

Grigorev, I., Kunickaya, O.G., Prosuzhih, A., Kruchinin, I., Shakirzyanov, D., Shvetsova, V., Markov, O. and S. Egipko (2020). Efficiency improvement of forest machinery exploitation. *Diagnostyka*, **21(2):** 95-109.

Janulevičius, A. and V. Damanauskas (2015). How to select air pressures in the tyres of MFWD (mechanical front-wheel drive) tractor to minimize fuel consumption for the case of reasonable wheel slip. *Energy*, **90:** 691-700.

Kachinskii, N.A. and I.V. Tyurin (1966). Mechanical and microaggregate composition of soils: Methods of investigation. Jerusalem (Israel) IPST.

Kotroczó, Z., Juhos, K., Biró, B., Kocsis, T., Pabar, S.A., Varga, C. and I. Fekete (2020). Effect of detritus manipulation on different organic matter decompositions in temperate deciduous forest soils. Forests, **11(6):** 675.

Kuvshinov, N.M. (2017). The efficiency of application of agricultural implements with active working bodies as methods of presowing cultivation of grey forest soils of non-Chernozem zone of Russia. *Vestnik of Bryansk State Agricultural Academy*, **1(59):** 23-31.

Lee, H. and S. Taheri (2017). Intelligent tyres? A review of tyre characterization literature. *IEEE Intelligent Transportation Systems Magazine*, **9(2):** 114-135.

Marra, E., Cambi, M., Fernandez-Lacruz, R., Giannetti, F., Marchi, E. and T. Nordfjell (2018). Photogrammetric estimation of wheel rut dimensions and soil compaction after increasing numbers of forwarder passes. *Scandinavian Journal of Forest Research*, **33(6):** 613-620.

Marusiak, M. and J. Neruda (2018). Dynamic soil pressures caused by travelling forest machines. *Croatian Journal of Forest Engineering: Journal for Theory and Application of Forestry Engineering*, **39(2):** 233-245.

Ogrin, G., Spinelli, R., Magagnotti, N., Halilović, V. and M. Mihelič (2020). Phytocenoses as indicators of the susceptibility of forest soils to ground-based forest harvesting machinery. *Acta Silvae et Ligni*, **123:** 31-41.

PressurePro (2021). Pulse generation. https://pressurepro.us/product-pulse.html

PSI ATIS (2021). Official web site. http://www.psityreinflation.com

Riggert, R., Fleige, H. and R. Horn (2019). An assessment scheme for soil degradation caused by forestry machinery on skid trails in Germany. *Soil Science Society of America Journal*, **83:** S1-S12.

Romanova, I.N., Prudnikov, A.G. and E.A. Tereshchenkova

(2007). Agrophysical properties of sod-podzolic soils and yield of spring wheat depending on predecessors. *Grain Farming*, **6:** 14-15.

Safonov, V.A., Danilova, V.N., Ermakov, V.V. and V.I. Vorobyov (2019). Mercury and methylmercury in surface waters of arid and humid regions, and the role of humic acids in mercury migration. *Periodico Tche Quimica*, **16(31):** 892-902.

Safonov, V.A., Ermakov, V.V. Degtyarev, A.P. and N.N. Dogadkin (2020). Prospects of biogeochemical method implementation in identifying rhenium anomalies. In IOP Conference Series: Earth and Environmental Science, IOP Publishing, **421(6):** 062035.

Stemco (2021). Official web site. https://www.stemco.com

TyreVigil Cloud. (2021). Official web site. https://www.tyrestamp.com/

TYREMAN Group (2021). Tyre pressure monitoring system PressurePro. https://tyreman.ru/pressure-pro

Valor TPMS (2021). Official web site. (http://www.valortpms.com/

Zaimes, G.N., Kasapidis, I., Gkiatas, G., Pagonis, G., Savvopoulou, A. and V. Iakovoglou (2020). Targeted placement of soil erosion prevention works after wildfires. IOP Conference Series: Earth and Environmental Science, IOP Publishing, **612(1):** 012050.