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Research Paper

Vibration and air quality tests inside the tractor cabin

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ABSTRACT

The industry of the tractor manufacturing and their equipment is constantly developing technically and in the user safety and comfort realm. However, the problem of the vibrations, which could negatively influence the user's health, has not been resolved. The review of the literature shows that this topic is not popular among scientists. The second aspect is the potential exposure of a driver to the air pollutants inside the tractor's cabin. All of them, with long-term stay inside a tractor may pose threat to the health and life of farmers. In the paper, the results of investigation of vibration in a chosen tractor working in real (operating) conditions were presented. The main aim of the researches was to evaluate the level of driver's exposure to the vibrations generated by the working tractor, especially in the range of the resonant frequency with human organs and identifying places with better vibration damping systems should be implemented. In addition, during the tests micro atmosphere inside the tractor cabin was analyzed. The research focused on the presence of hydrocarbons from volatile organic compounds group (which are carcinogenic and mutagenic) and evaluated the level of driver's exposure to such pollutants.

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INTRODUCTION

Operators of agricultural machineries are subjected to a variety of changing conditions that negatively affect their health and comfort at work. The noise, Whole Body Vibrations (WBV), and air pollution are some of the most important factors which have impact on the person's life. The relationship between air quality in the driver's cabin and the incidence of respiratory and cardiovascular diseases has been already confirmed in an extensive body of research (Chio et al., 2007; Sram et al., 2011). Most of the air pollution in the driver's cabin is caused by volatile organic compounds (VOCs) (Fedoruk et al., 2003), which may contain carcinogenic substances such as benzene, ethylbenzene and styrene.

So far, the research on the air quality in the driver's cabin has been mostly focused on the means of public transport and privately owned cars (Chuang et al., 2013; Geis et al., 2009; Kardasz et al., 2016; Tartakovsky et al., 2013). According to the authors of this paper investigation, the researches for farm tractors have not been performed.

The vibration in farm tractors is mainly caused by the running engine and tractor's operation under load. The fact that farm tractor operators, who perform standard agricultural work and are exposed to the high level of WBV, remains a well-documented phenomenon (Lines et al., 1995; Marsili et al., 2002; Baesso et al., 2015).

These vibrations differ in terms of type and insensitivity. They may be transferred to the operator's body through the seat, floor and steering wheel. Four vibration characteristics are distinguished to have the most important influence on the human body: intensity, frequency, direction and duration (exposure time) of the vibration. The negative impact of WBV on the human body has also been confirmed in the extensive body of the research (Bovenzi, 2009; Seidel and Heide, 1986; Tiemessen et al., 2008).

The most frequent complaints reported due to the prolonged exposure to WBV include stomach discomfort and disorders of the spine. However, vibrations in the transverse and longitudinal directions have a more significant impact on the human body than vibrations parallel to the vertical direction (Loutridis et al., 2011). As far as vibration frequency is concerned, the most harmful vibrations occur in the frequency range of 2 to 6 Hz, as they correspond to resonant vibrations in human internal organs and in the spine (Pope and Hansson, 1992; Prasad et al., 1995). Seeing that, a farm tractor is the source of vibrations particularly harmful to the operator's body, as high vibration level and in the frequency between 0.5 and 10 Hz, is transferred to the operator's seat during field works. In addition, vibrations caused by the tires in contact with the ground have a frequency of 2 and 20 Hz (Prasad et al., 1995; Clijmans et al., 1998).

The regulations on the minimal requirements concerning a tractor operator's safe level of exposure to WBV are listed in European Parliament Directive 2002/44/EEC. Moreover, the illnesses that tractor operators suffer from due to the WBV have a significant impact on the economy. Lower back pain is the most frequent cause of inability to work among tractor operators below 45 years old and accounts for 20% of all work injuries. Thus, it generates substantial financial losses. Because of these facts, lowering WBV level during field work is an important goal not only for tractor operators and producers, but also for the governments.

State of the art farm tractors are equipped with a great number of elements that serve to lower vibrations. Some of them are: the seat and cab suspension systems (Ivo and Herman, 2001; Deprez et al., 2005), damping mechanisms, shock absorbers and front-axle suspensions (Marsili et al., 2002; Hostens et al., 2004; Hansson, 2002) not to mention the low-pressure modern tires (Mayr et al., 2004).

The factors which influence the type and level of vibrations that the tractor's operator is subjected to are: tractor mass and ballasts (Lines et al., 1995), tire elasticity characteristics and tire pressure (Mayr et al., 2004; Servadio et al., 2007), the type of seat and cushion as well as suspensions (Cutini et al., 2012; Burdorf and Swuste, 1993; Duke, Goss, 2007), tractor seat height above the ground (Mehta and Tewari, 2002), soil parameters (soil type, moisture content and temperature) (Gomez-Gil et al., 2014; Cuong et al., 2013) and tractor forward speed (Mehta et al., 2000; Bukta et al., 2002; Kumar et al., 2001). These research results have been obtained in the field conditions, using modern farm tractors. The ergonomic research was performed in two directions: examination of volatile organic compounds (VOCs) and measurement of those vibrations within the resonant frequency range of human organs, particularly the eyeball.

The main focus was put on the vibrations generated on the access road leading to the field, as this type of road frequently (also in this case) causes resonance in the suspension parts. Hence, it affects the entire vehicle. Vibration measurements were also performed in order to show the portion of vibrations from the drive mechanism transferred to the driver's seat. All assessments were performed on the same test object simultaneously.

MATERIALS AND METHODS

As the test object, the researchers used a modern, popular type of a 4-wheel tractor with a self-ignition medium power engine based on Common Rail injection system. During the tests, a tilling set (mass = 770 kg) and a biaxial trailer (mass = 1480 kg) with a load of 2000 kg were attached. The front drive was disconnected during the transport.

The tractor of the examination had an air-conditioned cabin. Its seat was equipped with air suspension in the vertical plane and with mechanical suspension in the plane consistent with the direction of motion. The tires used for the tests were of standard size and depth of thread was not less than 90% of the depth of new thread. The recommended tire pressures of 131.7 kPa in front tires (440/65R24) and 141.8 kPa in rear tires (540/65R34) were maintained.

Hawing analyzed vibrations in the NVH direction, a classical measuring circuit was used. It comprised of: uniaxial PCB 356A02 accelerometers, 4-channel NI 9215 data acquisition card. The acquisition card was connected to a laptop with the author's own software installed. It enabled signal acquisition, filtration and conditioning in order to distinguish the harmonics which is close to the resonant frequencies of human organs (Lyons, 2015).

Additional tests were performed to investigate the function of vibration transmission from the engine to the tractor's frame, body and passenger's seat. The reason was to identify the potential locations for additional damping elements. The measurements of volatile organic compounds inside the driver's cabin were conducted using a gas chromatography method.

Prior to chemical analysis, hydrocarbon samples had to be taken from the cabin. Since the driver's cabin contained only trace quantities of VOCs and their concentration in samples had to be increased, the sampling process continued for 2.5 hours and took the total time of vibration measurements. The sampling location was determined on the basis of European standard ISO/DIS 12219-1:3. Interior air of road vehicles -Screening method was used for the determination of emissions of volatile organic compounds from vehicle interior parts and materials - Micro-scale chamber method". Although the standard relates to road vehicles, the highest concentrations of pollutants in a tractor cabin, that is, in the interior air are recorded near the seat at the height of the driver's head. This was confirmed by CFD simulations (Servadio, Belfiore, 2013).

The samples were taken with a semi-automatic 2-channel aspirator using solid sorbent and active carbon. The air flow rate in the aspirator was set to 30 dm^3/h and remained constant throughout the sampling procedure. Parameters of researchers: airflow rate [dm^3/h] - 30,

Table 1: Comparison of max., min. and mean vibration acceleration values, as measured on the engine's body, the driving axle and driver's seat.

S/No.	Measurement location	Max. [mm/s^2]	Min. [mm/s^2]	Mean [mm/s^2]	Deviation from the value measured on the body (max. value) (%)
1.	Engine body	18,50	-17,28	0,0310	---
2.	Driver's seat	10,18	-9,95	0,0221	55
3.	Axle	0,16	-0,15	0,0047	0,9

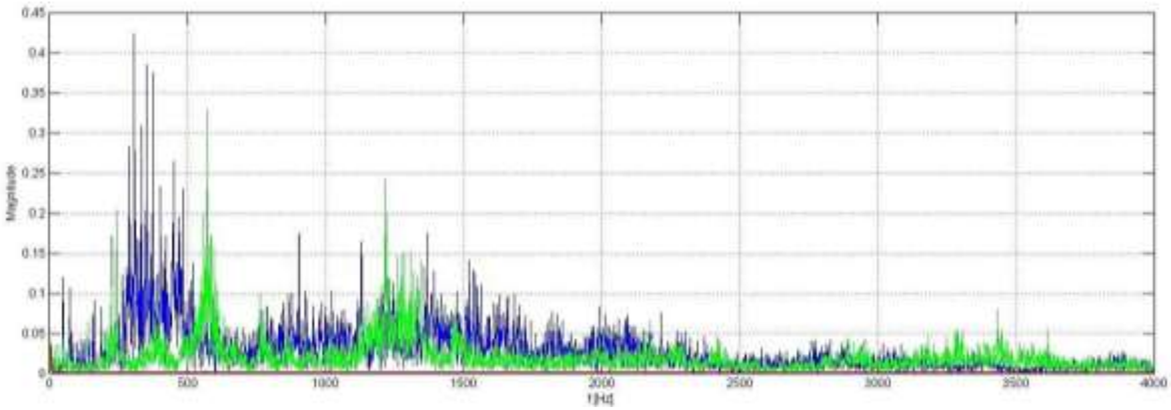

Figure 1: Vibration acceleration spectrum; the vehicle moved on tarmac surface with a velocity of 37 km/h; blue colour – acceleration value measured on the engine's body, green – on the driver's seat, red – on the driving axle.

sample time [h] – 2.5, total sampled air volume [dm^3] – 75.

RESULTS AND DISCUSSION

Results of vibration acceleration tests

The first set of the results presented shows the value of a generated vibrations which is transferred to the driver's seat and on the vehicle's driving axle. The vehicle moved on tarmacadam with a speed of 37 km/h (which corresponds to 2300 rpm).

The measured values were subjected to sampling and quantization without a process start indicator (for example, a TDC indicator). Therefore, the time histories cannot be compared directly. However, the maximum, minimum and average values for individual measurement locations can be established (Table 1). When it comes to the frequency domain using FFT transform, it enables one to exclude the imperfections which result from the lack of process start indicator. It is possible thanks to the one of the fundamental transform features, that is, the shift theorem (Zawiślak, 2013).

Another set of the presented results is related to the conditions of operation in three stages: at 31 km/h a) without any equipment attached (such velocity causes the vehicle's resonance due to the imbalance; b) with the trailer and c) with the (generator) tilling set. Figure 1 shows vibration acceleration spectrum, while Figure 2 presents the time domain of vibration for the aforementioned states (blue – in solitary, red – with the (generator) tilling set, green – the trailer), as measured on the engine's body.

The time-history analysis indicates that the vibrations transferred to the driver's seat are conditioned by damping systems. It contributes to their equalization in all the aforementioned states (Figure 3).

Finally, Fourier transform was performed for both aforementioned measurement locations. The spectrum was displayed in the range up to 150 Hz, that is, in the band which corresponds to the resonant frequencies of human organs (Lyons, 2015) (Figures 4 and 5).

Results of VOCs concentration inside the cabin

Since the chromatography method is a comparative method, the analysis results were collated with the calibration curves. They had been prepared beforehand and fed into the software for every standard. Calibration curves allow not only the identification of individual compounds (qualitative analysis), but also the calculation of their concentrations (quantitative analysis). The outcome of the analysis is visible on the chromatogram,

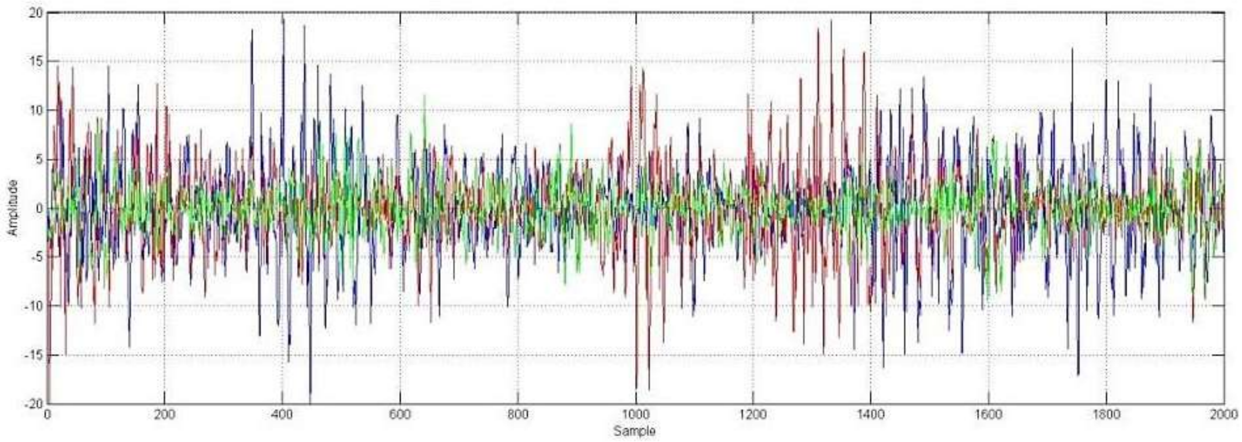

Figure 2: Time domain of vibration (tarmac, 31 km/h) measured on the engine's body; blue – in solitary, red – the (generator) tilling set, green – the trailer.

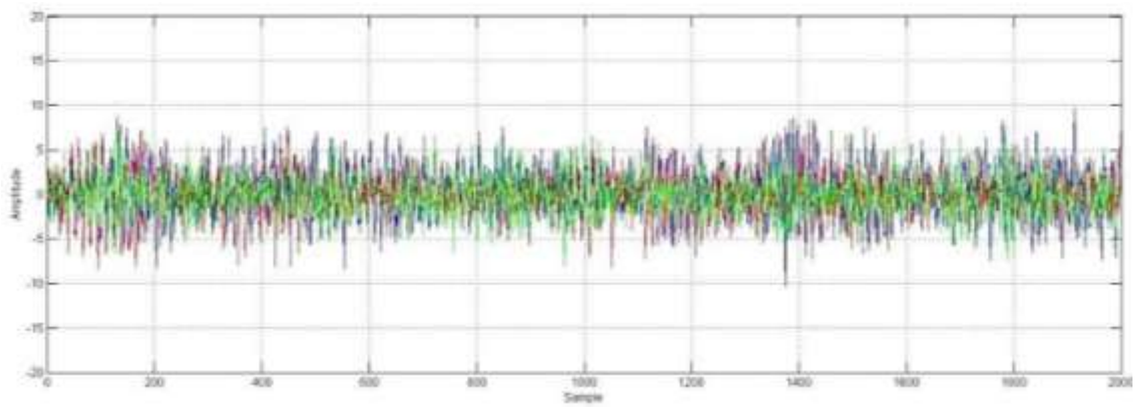

Figure 3: Time domain of vibration (tarmac, 31 km/h) measured on the driver's seat; blue – in solitary, red – the (generator) tilling set, green – the tráiler.

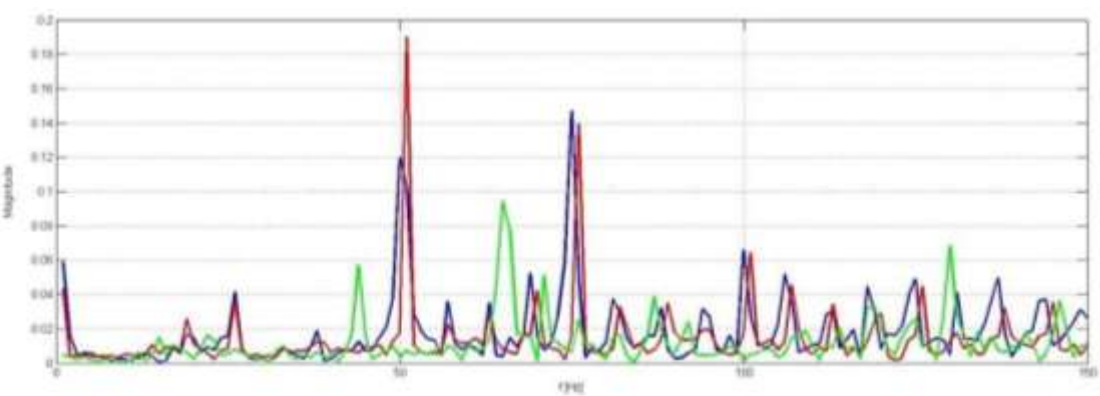

Figure 4: The Frequency domain of acceleration (tarmac, 31 km/h) measured on the engine's body; blue – in solitary, red – the (generator) tilling set, green – the trailer

which serves as a graphic representation of the results. The findings are also shown in the form of a table.

The study was repeated thrice and the concentration values were provided as an arithmetic average for all three repetitions. The concentrations which come directly from the software that cooperates with the chromatograph were given in parts per million (ppm) and relates to 2 ml of the solvent, that is, carbon disulphide used for

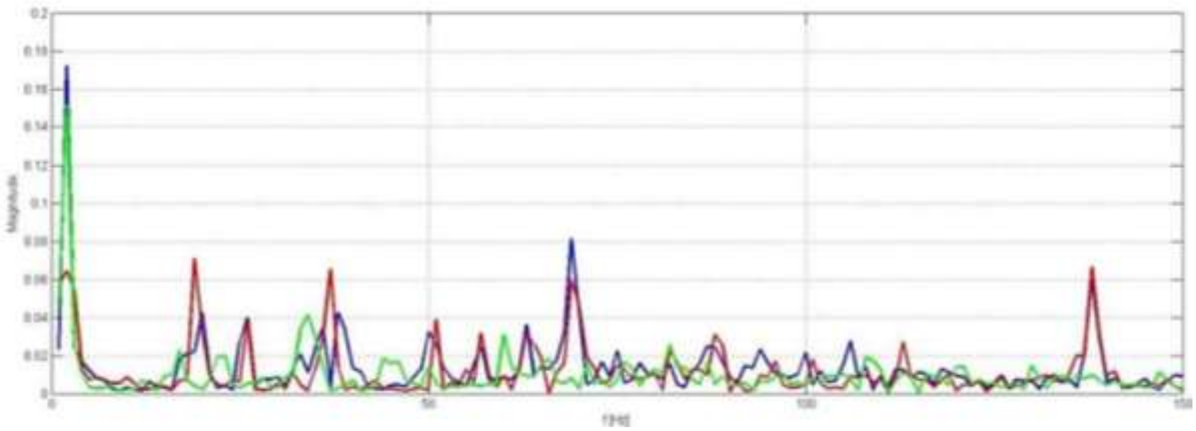

Figure 5: The Frequency domain of acceleration (tarmac, 31 km/h) measured on the driver's seat; blue – in solitary, red – the tilling set, green – the trailer.

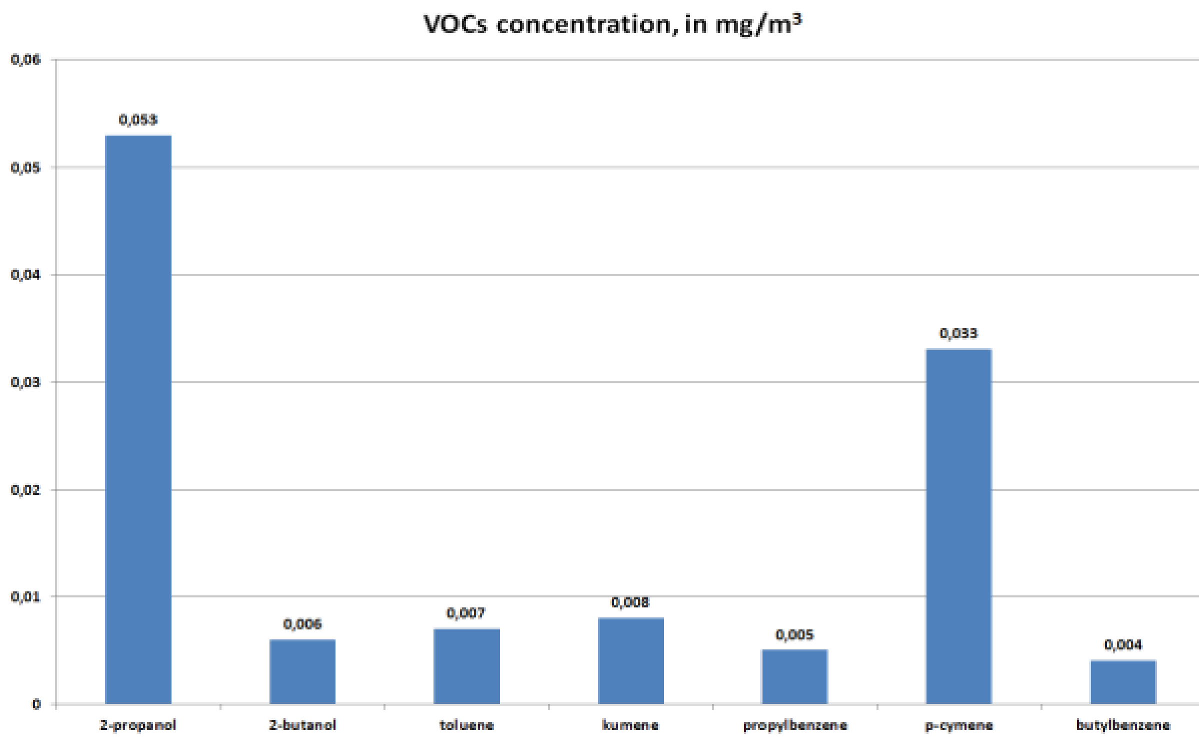

Figure 1: Concentrations of volatile organic compounds identified inside the tractor's cabin.

desorption. In order to obtain the concentration values for the pollutants analyzed in the cabin's air, it was necessary to conduct additional calculations. They take into account the volume of air which is actually passed through the aspirator. Figure 6 shows the results of the performed analyses and calculations.

Conclusions

The analysis of comparison results for vibration acceleration amplitude (in solitary, with the trailer and with the (generator) tilling set, as measured on the engine's body –(Figure 3) allows to observe that the maximum acceleration values are 24.2 mm/s^2 (in solitary), 20.8 mm/s^2 (with the (generator) tilling set), 12.6 mm/s^2 (with the trailer). In the case of the first value, it arises from the vehicle's imbalance. On the other hand, the result with the (generator) tilling set is due to high torque values which are required to keep the vehicle in motion.

The time-history analysis in Figure 4 indicates that the vibrations transferred to the driver's seat are conditioned by damping systems. Because of this fact, they equalize in all of the aforementioned states. However, a difference in maximum acceleration values is observed for the solo state (12.8 mm/s^2, which means 53% in relation to the engine's vibration in the same state). The state with the (generator) tilling set attached is characterized by the maximum acceleration value of 9.6 mm/s^2, which is 46% in relation to the same state measured on the engine's body. The unloaded biaxial trailer attached to the tractor produces the maximum acceleration value of 8.3 mm/s^2, which is 66% of the value measured on the engine's body. To conclude, these findings are consistent with the results of research on new vibration damping systems in farm tractors (Cuong et al., 2013) Nevertheless, the problem remains unsolved, especially when heavy working equipment is attached.

The outcomes of this research are also consistent with the published results of research on the influence of velocity on the RMS value of acceleration (Prasad et al., 1995). However, the influence that tire pressure has on vibration damping proves to be of marginal importance while comparing to other variables (for example, agricultural machinery attached).

The comparison of both spectra confirms the conclusions from the time-history analyses, that is, the vibrations were damped in the range of 50 to 60%. It concerned the acceleration measured on the engine's body (Figure 5) and on the driver's seat (Figure 6), especially within the range corresponding to the resonance frequencies of human organs (the frequencies of interest were assumed not to exceed 150 Hz). The aforementioned results point to the need for further research on vibration damping systems. The problem remains unsolved despite several decades of work (Clijmans et al., 1998).

Finally, the tests performed inside the tractor's cabin led to the identification of a total number of seven compounds classified as VOCs. The measured concentrations for each of the compounds are not high and none of the compounds exceeded the TLV-TWA and TLV-STEL values. Nonetheless, these compounds may pose a threat to health even in small concentrations, if the exposure time is significantly long. It should be born in mind that despite such a limited sampling time (only 2.5 h), volatile organic compounds in the cabin, have been identified.

Moreover, during the sampling procedure the tractor performed only one type of field task and neither fertilizers nor other additional chemical substances were used. The threat to the driver's health is likely to rise substantially in the case of working for longer periods of time and using additional chemical substances (for example, fertilizers).

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