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Studies of farmers' annual exposure to whole body vibration on selected family farms of mixed production profile

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Abstract

The objective of the study was to recognize and evaluate the annual exposure of private farmers to whole body mechanical vibration on selected family farms of mixed production profile (plant-animal). The scope of study covered the carrying out of time schedules of agricultural activities, and measurements of the frequency weighted vibration acceleration (m/s^2), expressed as effective values (r.m.s.) for each of three spatial directions on the seat surface within the period of the whole year. The basic vibration parameter was vibration dose (d). The following values were determined: total monthly vibration dose, mean equivalent daily vibration dose, and mean equivalent daily vibration acceleration. The highest values of the total monthly vibration dose (d) were observed in April and August (55.3-56.7 $m^2/s^4 \cdot h$). The mean equivalent of daily vibration acceleration showed the highest values in four months of the year: April, August, September and October (0.49-0.60 m/s^2); the average value of this parameter for the whole year reached the level of 0.44 m/s^2 – below the standard. Due to the occurrence in agricultural vehicles of mechanical shocks (mean values of maximum vibration acceleration: 0.82-1.00 m/s^2; exceeding the standard), and exceeding of the *daily exposure action value,* proper steps should be undertaken with respect to the protection of private farmers against risk resulting from exposure to mechanical vibration while performing work activities.

Key words

whole body vibration, vibration acceleration, vibration dose, annual exposure, private farmers, mixed production (plant-animal)

INTRODUCTION

Mechanical whole body vibration, apart from noise, [1, 2] is an important physical hazard occurring in the work environment of a farmer. The principal sources of this type of vibration are agricultural vehicles, including primarily wheel-type agricultural tractors (Polish and foreign producers), of a wide range of power spectrum, and self-propelled farm machines (mainly combine harvesters, as well as self-propelled forage harvesters for green or mowers (swathers), and beet combine harvesters). This vibration occurs on the seats of agricultural machinery in operation, while performing specified field and transport work activities [3, 4, 5, 6, 7].

Previously conducted preliminary studies of mechanical vibration [7] emitted by agricultural vehicles confirmed that vibration patterns occurring on seats while performing such work activities as: hay tedding and raking, spreading of fertilizers, aggregation of soil, grass mowing and cultivation may create a special risk for farmers' health. These work activities are performed at elevated tractor speeds, most often over a hardened and uneven surface.

Relatively few environmental studies have shown that the highest vibration levels measured at the seats of agricultural tractors remained mainly within the range of low frequencies (1-10 Hz), overlapping with the resonance frequencies of organs and various parts of the human body. Mechanical vibration of such characteristics may be the cause of serious disorders in the functioning of these organs and systems, and in the case of such a high intensity of the mechanical stimulus may lead to their damage. This is explained by the transition of tissues and organs with respect to each other, which results in stretching or compression of the ligaments, connective tissue in joints or intervertebral discs.

The data from literature show [8, 9, 10] that the long-term effect of whole body mechanical vibration may cause a number of non-specific changes of various character in the human body, within organs and systems (motor system, digestive system, female reproductive system, sense organs, and the peripheral circulatory system). Nevertheless, increasingly more frequently reports are published concerning disorders in the spine region, reported by workers exposed to whole body vibration, including farmers [11, 12, 13, 14, 15, 16, 17, 18]. Farmers most often complain of pain in the lumbar section of the spine [19, 20, 21, 22, 23, 24, 25]. Changes in the spine diagnosed by radiological tests concern discopathy and degenerative deformation of the vertebrae and joints, which may be due to the effect of whole body mechanical vibration. A higher degree of spine impairment in this occupational group may result from the occurrence of mechanical shocks in farmers' occupational environment [7, 26].

To-date, international and Polish literature concerning the recognition of risk caused by whole body vibration among farmers' is relatively scarce. This is primarily caused by a great complexity and changeability of vibration phenomena

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in the rural environment (large number of various field activities performed on uneven surfaces, with the use of various agricultural vehicles, during the whole year), and high costs of performance of these studies. In Poland, due to the legal regulations in effect, the institutions founded for these studies (sanitary inspectorate and labour inspectorate) do not perform such research; hence serious problems with the adjudication of occupational diseases caused by the whole body vibration.

Due to a large number of field and transport work activities performed in different meteorological and soil conditions and changeable time of daily exposure to vibration, the only adequate method for assessment of the degree of risk caused by whole body vibration is the performance of studies during the whole calendar year. Evaluation of farmers' annual exposure to whole body vibration from the aspect of the type of agricultural production (plant, animal, mixed) is a new, and a relatively poorly recognized problem, both in Poland and abroad [24].

In order to recognize and evaluate the annual exposure to mechanical vibration among private farmers on selected family farms of a mixed-production profile (plant-animal), investigations were undertaken within grant project [27], this problem being the objective of the presented study.

MATERIAL AND METHODS

The studies covered 25 family farms selected in the area of two communes (Niemce and Mełgiew), using arable land of the size: 13-30 ha (20.4 ha on average), engaged in plant-animal production. These farms were equipped with 73 medium, high and low power tractors, the majority were medium-power tractors (C-360, U-4512; 26 tractors).

The selected farms were engaged in the production of cereals, sugar beets, sweet corn, green forage and hay, and cattle breeding (18 cows on average), or swine breeding (38 swine on average).

The scope of study covered as follows:

- carrying out time-schedules of agricultural activities performed by farmers on their own farms, during which there occurred exposure to vibration (these measurements were performed by farmers under the supervision and control of the research team from the Institute);
- measurements of frequency weighted vibration accelerations (m/s^2), expressed as Root Mean Square values (RMS), for each of the three axes on the seat surface.

Both time-schedule and vibration measurements were carried out while performing by farmers basic field and transport activities, during the whole calendar year.

In the studies, the SVANTEK scientific instrument was used, which satisfied the research requirements, including: SVAN 912 AE portable sound and vibration analyzer, SV 06A four-channel module, and Emsonmat PD 3s triaxial seat sensor. The devices were equipped with correction filters, referring to the three spatial vibration directions, and marked by the symbols: W_k (whole body vibration, vertical, 'Z' axis) and W_d (whole body vibration, horizontal 'X' or 'Y axes), which allowed the obtaining of frequency corrected vibration acceleration.

In order to evaluate the level of farmers' exposure to whole body mechanical vibration, a vibration parameter was used [28, 29] called a vibration dose (d), calculated by means of the following formula:

$$d = \sum_{i=1}^{n} a^2_{w,i} \cdot t_i$$

where:
d – vibration dose;
$a_{w,i}$ – frequency corrected dominant value of vibration acceleration, with consideration of adequate direction coefficients (1,4 $a_{w,x}$, 1,4 $a_{w,y}$, $a_{w,z}$), within the time interval i (m/s^2);
t_i – vibration time within the time interval i (hour.);
n – number of time intervals.
i – time interval.

The definition of vibration dose contains two physical values – vibration intensity expressed by frequency weighted acceleration values $a_{w,i}$, and vibration duration t_i within the specified time intervals i. The vibration unit is: m^2/s$^4 \cdot$h.

Based on precise time-schedules performed and results of measurements of vibration acceleration, data was obtained which is evidence of the level of farmers' exposure to whole body vibration, and the duration of exposure to vibration in individual months of the year. The following values were determined for the calculated vibration dose (d): total monthly vibration dose, and mean equivalent daily vibration dose (referring to the legal workdays monthly). The mean equivalent daily vibration dose (for an individual month) is the value obtained from the ratio of total monthly vibration dose and number of legally established workdays in a given month.

Statistical analysis was performed by means of SPSS/PC computer software [30]. The following statistical parameters were analyzed: normality of distribution (skewness, kurtosis, Kolmogorov-Smirnov test), and the mean values (arithmetic), the degree of data dispersion (range, standard deviation, confidence intervals). In order to determine the degree of variation of the results of studies obtained, the analysis of variance was performed (single-factor ANOVA) by F test, calculated as a ratio between extra-group to intra-group variation (independent samples, of normal distribution, possessing homogenous variance), expressed as the mean sum of squares. Leven test was applied to investigate the homogeneity of variance. For the assessment of differences occurring between the mean values obtained, referring to individual months of the year, Duncan's multiple range test was used. For all the tests applied, the statistical significance level was set at $p \geq 0.05$ (in the case of Kolmogorova-Smirnov test it means that data distribution fulfils the requirements of normal distribution; for Leven test – indicates homogeneity of variance; while for Duncan test – means the lack of significant differences between mean values).

RESULTS

The basic statistical data concerning total monthly dose of mechanical vibration (mixed production) in individual months of the calendar year were compiled in Table 1. The data presented show the occurrence of great changeability of the results of studies and their high variation. The highest data dispersion was obtained in April, August and December; which is evidenced by a high range of the values measured (maximum up to: 101.9-139.9 units; according to an individual month), high values of kurtosis coefficients

Table 1. Statistical values of total monthly dose of mechanical vibration (d) [$m^2 \cdot s^{-4} \cdot h$]

Months	Mean±SD	CI	α	k	Range	p
January	13.62±9.50	7.59-19.67	1.29	0.77	5.59-34.68	0.53
February	13.28±6.54	10.03-16.53	0.82	0.05	4.30-28.23	0.65
March	19.59±11.58	14.45 -24.72	1.48	2.56	4.68-54.27	0.52
April	55.27±21.53	46.58-63.97	0.78	0.52	19.97-103.82	0.33
May	35.11±21.52	26.22-43.99	0.94	1.29	3.54-95.40	0.90
June	33.66±17.43	26.47-40.86	0.79	0.57	5.99-80.39	0.94
July	22.25±16.23	15.39-29.10	1.53	3.46	1.36-74.55	0.48
August	56.65±29.89	44.58-68.73	1.23	1.57	17.75-139.98	0.41
September	44.74±22.37	35.55-53.93	0.60	0.51	10.58-100.70	0.72
October	43.96±21.00	35.47-52.44	0.56	-0.60	12.40-88.25	0.63
November	28.47±16.61	21.76-35.18	0.71	0.02	5.16-70.12	0.64
December	20.24±23.30	7.83-32.66	3.19	11.41	1.40-101.90	0.16
For whole year	32.24±15.24	22.55-41.92	0.38	-1.15	13.28-56.65	0.92

Mean – mean arithmetic value; SD – standard deviation; CI – confidence interval;
α – skewness coefficient; k – kurtosis; Range – (min–max) range;
p – probability normal distribution.

(k = 0.52-11.41) and skewness (α = 0.78-3.19) and elevated values of standard deviations (with respect to mean values). Despite such dispersion, the data distribution in these months still remain within the range of normal distribution (Kolmogorov-Smirnov test: p = 0.16-0.41). A better data distribution, similar to the normal distribution (p = 0.48-0.72) was noted in January, February, March, July, September, October and November (lower values of the statistical parameters analyzed above). Considerably the best data distribution, closest to the normal distribution (p = 0.90-0.94), was noted in May and June (the smallest standard deviations, low values of kurtosis and skewness coefficients, and small range of the values measured – with relation to the mean values).

In order to assess within what interval, at an established level of confidence, the actual mean monthly vibration dose may be expected, confidence intervals were calculated (for the adopted level of confidence equal 95% and two-sided t-Student test, 2.5% of confidence level at each side). Confidence intervals within which the mean values are comprised (Tab. 1), cover a relatively varied range, according to an individual month. The greatest width of the confidence interval was observed in two moths: January and July (the ratio between the upper confidence limits to mean values assumes the data: 1.31-1.44; which is equivalent in a logarithmic scale to the value of: 1.2-1.6 dB). Changing a scale from linear to logarithmic consists in the conversion of data according to the formula: $L_{dB} = 10 \log CI_{max}/Mean$; where CI_{max} – is the value of upper confidence limit; Mean – mean arithmetic value.

In the remaining months (10 months), the width of confidence interval was smaller, while the ratio of the upper confidence limits to the mean values were from 1.16-1.26 (0.6-1.0 dB).

Analysis of variance (ANOVA) performed for the total monthly vibration doses showed that variances determined in individual months significantly differed statistically (test F = 12.83; p = 0.0001). Also, the Leven test for homogeneity of variance confirmed that the mean values obtained were characterized by varied homogeneity (S = 2.566; p = 0.004). The analysis of the significance of the differences between individual months performed by means of Duncan's test showed that there was no variation between mean total doses in January, February, March, July and December (p = 0.192); March, July, November and December (p = 0.184); May, June, July and November (p = 0.052); May, June, September, and October (p = 0.096); and April, August, September and October (p = 0.055).

Mean arithmetic values were selected for the analysis and hygienic evaluation of average doses of mechanical vibration to which private farmers are exposed, as the most adequate from the aspect of mechanical energy. The highest values of the mean (arithmetic) total vibration dose were noted in April (55.27 $m^2/s^4 \cdot h$) and August (56.65 $m^2/s^4 \cdot h$); whereas the lowest values were observed in January (13.62 $m^2/s^4 \cdot h$), February (13.28 $m^2/s^4 \cdot$ hour), March (19.59 $m^2/s^4 \cdot h$) and December (20.24 $m^2/s^4 \cdot h$).

High values of mean total vibration doses in August could be explained by the great intensification of work activities associated with harvesting of cereals, soil cultivation and transport of agricultural products (mean value of the total time of exposure to mechanical vibration in this month was: 83.4 h) (Fig. 1). These work activities are characterized by the emission of vibration of high accelerations (this especially refers to transportation activities performed most often in this month) (Fig. 2). This is due to the large number of workdays in conditions of exposure to vibration in this month (19.7 days on average) (Fig. 3), and frequently prolonged duration of exposure on those workdays (4.3 h daily on average; maximum up to 9.3, Fig. 4; in single cases up to 16.3 h).

High values of vibration doses in April result from both the prolonged time of exposure to vibration (mean total time: 77.7 h), large number of workdays (17.5 on average), prolonged duration of exposure (4.6 h daily on average; maximum up to 9.0 h; in single cases up to 16.3 h), and the performance of work activities characterized by the emission of high acceleration vibration in this month (transport, tedding and raking hay, disc harrowing, spreading of fertilizers, spraying) (Fig. 2).

In the case of mean value referring to the whole calendar year (Tab. 1), the mean monthly vibration dose was 32.24 ± 15.24 $m^2/s^4 \cdot h$, with the distribution of data equivalent to the normal distribution (Kołmogorov-Smirnov test; p = 0.92).

A more objective indicator of exposure, equivalent to the actual exposure to mechanical vibration is the value of the mean equivalent daily vibration dose, referred to the legally established workdays in each month (40 – work hour week; holidays and Saturdays free of work). As a result of calculations performed, statistical data was obtained concerning this parameter (Tab. 2). The variation of the mean equivalent daily vibration dose was considerably smaller, compared to the total monthly vibration dose discussed (for the arithmetic mean it remained within the range 0.62-2.83 $m^2/s^4 \cdot h$).

The greatest data dispersion was noted, as previously, in three months of the year, in April, August and December, which is evidenced by a high range of the mean values obtained (range) (maximum: 4.72-7.00 units; in individual months), high values of kurtosis coefficients (k = 0.53-11.41) and skewness (α = 0.78-3.19), and high values of standard deviations (compared to the mean values). Despite such a dispersion, the distribution of data in these months still remained within the range of normal distribution (Kolmogorov-Smirnov test: p = 0.16-0.42).

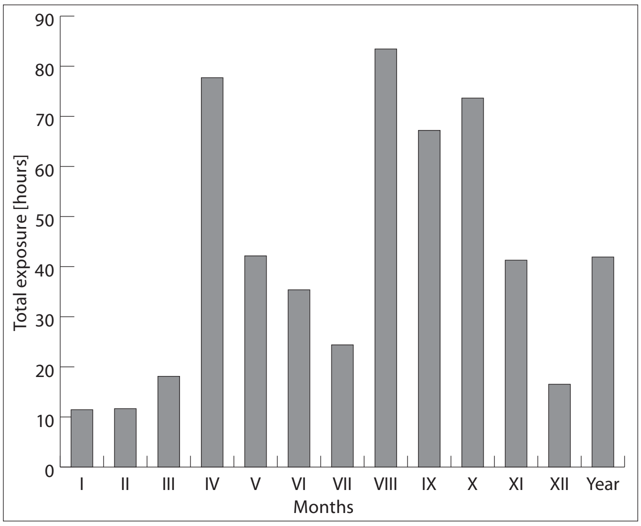

Figure 1. Mean values of total exposure (hours) in individual months

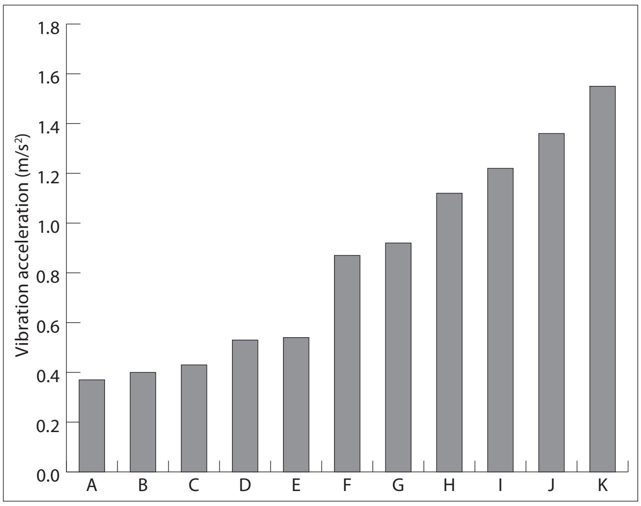

Figure 2. Equivalent values of vibration acceleration for different work activities. (A – cutting and grinding of maize; B – combine harvesting of cereal crops; C – beetroot digging; D – working with tractor front loader; E – potato digging; F – spreading of fertilizers; G – grass mowing; H – disk harrowing; I – transportation of manure (field road); J – hay tedding and raking; K – transport 2 trailers (asphalt road)

Table 2. Statistical values of mean equivalent daily dose of mechanical vibration (d) [$m^2 \cdot s^{-4} \cdot h$]

Months	Mean±SD	CI	α	k	Range	p
January	0.62±0.43	0.34-0.89	1.29	0.77	0.25-1.58	0.55
February	0.63±0.31	0.48-0.79	0.82	0.03	0.20-1.34	0.64
March	0.98±0.58	0.72-1.24	1.47	2.51	0.23-2.71	0.54
April	2.51±0.98	2.12-2.91	0.78	0.53	0.91-4.72	0.34
May	1.76±1.08	1.31-2.20	0.94	1.29	0.18-4.77	0.89
June	1.60±0.83	1.26-1.94	0.79	0.58	0.28-3.83	0.93
July	0.97±0.71	0.67-1.26	1.53	3.45	0.06-3.24	0.48
August	2.83±1.50	2.23-3.44	1.24	1.57	0.89-7.00	0.42
September	2.03±1.01	1.62-2.45	0.60	0.49	0.48-4.57	0.71
October	1.91±0.91	1.54-2.28	0.56	-0.60	0.54-3.84	0.63
November	1.50±0.87	1.14-1.85	0.71	0.03	0.27-3.69	0.64
December	0.97±1.11	0.37-1.56	3.19	11.41	0.07-4.85	0.16
For whole year	1.53±0.72	1.07-1.98	0.41	0.76	0.62-2.83	0.76

Mean – mean arithmetic value; SD – standard deviation; CI – confidence interval;
α – skewness coefficient; k – kurtosis; Range – (min–max) range;
p – probability normal distribution.

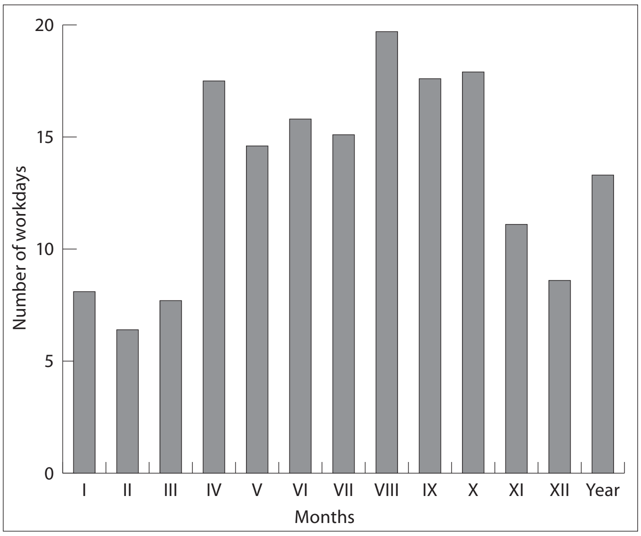

Figure 3. Mean number of workdays during a month in conditions exposure to vibration

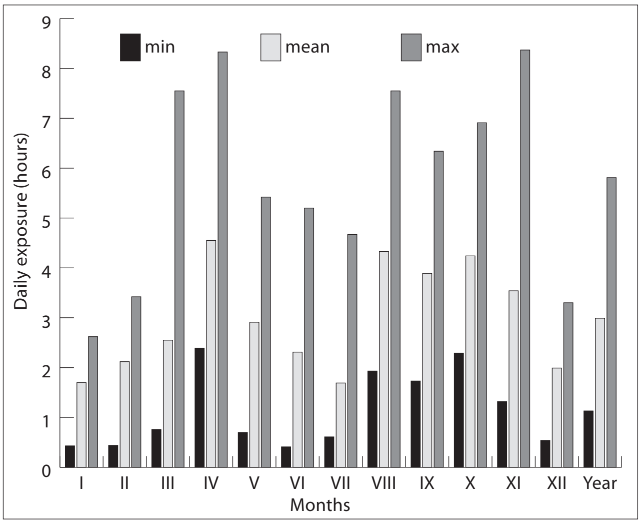

Figure 4. Daily exposure (hours) to vibration in individual months

A better data distribution, similar to normal distribution (p = 0.48 – 0.64), was noted in January, February, March, July, October and November (lower values of the statistical parameters analyzed above). Considerably the best data distribution, and the closest to the normal distribution (p = 0.71 – 0.93), was observed in May, June and September (the lowest standard deviation, low kurtosis and skewness coefficients, and the smallest range of the values measured – with relation to the mean values).

Calculated values of the confidence interval for this vibration parameter maintained a distribution similar to monthly exposure. The widest confidence interval was obtained in January, July and December (the ratio between the values of the upper confidence limits and the mean values adopting data within the range: 1.30-1.61; which in the logarithmic scale is equivalent to: 1.1-2.1 dB). In the remaining months (9 months), the width of the confidence interval was smaller, and the ratio of the upper confidence limits to mean values were: 1.16-1.27 (0.6-1.0 dB).

Analysis of variances specified in individual months of the year for the weighted daily vibration dose showed that these variances significantly differed statistically (F test = 12.53;

p = 0.0001). Also, the Leven test for homogeneity of variance indicated that the mean values obtained are characterized by a varied homogeneity (S = 3.193; p = 0.001). However, studies of the significance of the differences between individual months by means of the Duncan's test confirmed that there was no variation between the mean values of the weighted daily vibration doses in January, February, March, December and July (p = 0.274); December, July, March and November (p = 0.093); November, June, May, October and September (p = 0.099); September and April (p = 0.097), and April and August (p = 0.268).

Analysis of the data obtained shows that the highest mean value (arithmetic mean) of the equivalent daily vibration dose was observed in April (2.51 $m^2/s^4 \cdot h$), August (2.83 $m^2/s^4 \cdot h$), and September (2.03 $m^2/s^4 \cdot h$), whereas the lowest – in January (0.62 $m^2/s^4 \cdot h$), February (0.63 $m^2/s^4 \cdot h$), March (0.98 $m^2/s^4 \cdot h$), July (0.97 $m^2/s^4 \cdot h$) and December (0.97 $m^2/s^4 \cdot h$).

High values of vibration doses in August and September result from high intensity of transport activities performed, characterized by emission of high acceleration vibration, duration of daily exposure to vibration and a considerable number of workdays in these months.

In April, there dominate transport activities of considerable intensity, as well as hay tedding and raking, spraying, and work associated with soil management (cultivation, disc harrowing); these are tasks performed with high vibration levels. In this month there also occurs long-term exposure to mechanical vibration (long time of monthly exposure, prolonged duration of daily exposure, large number of workdays a month).

In order to evaluate the degree of farmers' exposure to mechanical vibration, the obtained values of the equivalent daily vibration dose in individual months of the year were recalculated into vibration acceleration values – energy equivalent and frequency weighted, for 8-hour daily exposure. Table 3 presents the data obtained in this way. The mean values of vibration acceleration (mean daily exposure), according to individual months, remained within the range: 0.28-0.60 m/s^2; with the highest values observed in April, August, September and October (0.49-0.60 m/s^2), while the lowest values concerned January, February, March and December (0.28-0.35 m/s^2).

Compared to the standard values (standard: A(8) = 0.8 m/s^2) [31] the values of mean daily exposure to vibration noted remained below allowable levels for all months. This also concerns acceleration values within the confidence interval (CI). Also, the mean value calculated for the whole year – mean daily exposure to vibration (0.44 m/s^2 ± 0.30) – did not exceed allowable values. The upper limits of vibration acceleration within the range for certain months were close to the standard (December: 0.78 m/s^2), or exceed the standard (August: 0.94 m/s^2).

Due to the high contribution of mechanical vibration shocks in the patterns registered [7, 27], creating a high risk for the spine of operators of agricultural vehicles, in the hygienic evaluation of the degree of vibration risk, maximum vibration acceleration values cannot be omitted (induced by shocks), which in the case of mixed production obtain mean values within the range: 0.67-1.00 m/s^2 (Tab. 3). For six months (April, May, June, August, September and October) these values exceed the allowable levels, reaching: 0.82-1.00 m/s^2; especially in April (0.98 m/s^2) and August (1.00 m/s^2). In addition, the occurrence of the highest momentary maximum vibration acceleration values were observed: 1.40-1.48 m/s^2 in April, August and September, and 1.23-1.27 m/s^2 May, June, October and November.

The latest Polish legal regulations [32] concerning work safety and occupational hygiene while performing work activities associated with exposure to mechanical vibration, which are a basis for the Directive 2002/44/EC of the European Parliament [3], define the *action value for daily exposure* to the whole body vibration at the level: $A(8)_w = 0.5$ m/s^2, the exceeding of which obliges the employers to undertake specified preventive actions.

In the light of the measurement data obtained, it should be stated that the values of mean daily exposure to vibration registered exceed the *action value* in August (0.60 m/s^2) and April (0.56), and remain on the threshold of allowable value in September. Maximum values of vibration acceleration exceeded the allowable *action value* in all months of the year.

Table 3. Statistical values of energy equivalent for an 8-hours daily exposure, frequency of weighted vibration acceleration [m/s^2].*

Months	Mean±SD	CI	Range	Maximum values	
				means	max instantaneous
January	0.28±0.23	0.21-0.33	0.18-0.44	0.67	0.98
February	0.28±0.20	0.24-0.31	0.16-0.41	0.70	0.90
March	0.35±0.27	0.30-0.39	0.17-0.58	0.77	1.02
April	0.56±0.35	0.51-0.60	0.34-0.77	0.98	1.48
May	0.47±0.37	0.40-0.52	0.15-0.77	0.82	1.25
June	0.45±0.32	0.40-0.49	0.19-0.69	0.88	1.23
July	0.35±0.30	0.29-0.40	0.09-0.64	0.76	1.18
August	0.60±0.43	0.53-0.66	0.33-0.94	1.00	1.43
September	0.50±0.36	0.45-0.55	0.24-0.76	0.92	1.40
October	0.49±0.34	0.44-0.53	0.26-0.69	0.88	1.27
November	0.43±0.33	0.38-0.48	0.18-0.68	0.79	1.27
December	0.35±0.37	0.22-0.44	0.09-0.78	0.73	0.98
For whole year	0.44±0.30	0.37-0.50	0.28-0.59	0.83	1.20

Mean – mean arithmetic value; SD – standard deviation; CI – confidence interval; Range – (min–max) range.
*Converted from the value of equivalent daily vibration dose given in Table 2.

DISCUSSION

The studies of annual exposure of private farmers specializing in mixed production (plant-animal) to whole body mechanical vibration showed great complexity and changeability of the results within a time interval which covered the entire calendar year. This is associated primarily with the type of agricultural and transport work activities performed within proper time intervals.

The degree of loading private farmers with mechanical vibration is conditioned, on the one hand, by the level of vibration transmitted from the seat of vehicle to the whole body of an operator, and on the other hand, the duration of exposure to this factor within a proper time interval.

The results of the study showed that the highest values of the total vibration dose (d) occurred in the spring-summer months (April, August). High values of total vibration doses in August can be explained by the high intensity of work activities associated with harvesting of cereals, soil management, and transport of agricultural products (prolonged duration of exposure, vibration at high acceleration). In April, transport activities, hay tedding and raking, disc harrowing, spreading of fertilizers and chemical treatment are performed, also emitting high values of vibration accelerations, accompanied by long-term exposure. The results of the study clearly confirm the rule that in order to obtain a genuine and representative evaluation of the degree of whole body vibration risk among private farmers, the full production cycle should be examined, covering the period of the whole year, and all the types of agricultural and transport activities performed.

The calculated mean equivalent value of daily vibration acceleration showed the highest values during four months of the year: April, August, September and October (0.49-0.60 m/s^2); whereas the lowest values were noted in January, February, March and December (0.28-0.35 m/s^2). The average value of this parameter for the whole year was 0.44 m/s^2 (below allowable values).

Earlier preliminary studies concerning mechanical vibration emitted by agricultural vehicles, conducted by the author of the presented study [7], showed that a special risk for farmers' health may be created by mechanical vibration occurring on seats while performing such work activities as: hay tedding and raking (0.94-1.12 m/s^2), spreading fertilizers (0.87-1.35 m/s^2), soil aggregation (0.87-1.12 m/s^2), grass mowing (1.05 m/s^2) and soil management (0.46-0.99 m/s^2). These are work activities performed at elevated working speeds of tractors, most often over a hardened and uneven surface.

The results of studies of whole body vibration conducted by other authors are most frequently presented in the form of the parameter called a vector sum of frequency-weighted acceleration (the root-sum-of-squares of the values for three directions of vibration). According to Boshuizen et al. [13], while driving a tractor over a hardened surface accelerations are emitted of the value 1.1 m/s^2, whereas while driving over a field: 0.6 m/s^2. Bovenzi and Betta [19], and Bovenzi and Hulshof [14] obtained, according to tractor type, vibration acceleration on seat on the level of 0.89-1.41 m/s^2, while Sandover et al. [34] obtained values of 0.35-1.45 m/s^2. These data are similar to the values obtained by the author of the presented study in his first report [7].

Despite the fact that the mean values of daily exposure to vibration obtained in the presented study remain below the allowable levels (standard: A(8) = 0.8 m/s^2), considering the occurrence of mechanical shocks in agricultural vehicles (creating risk for operator's spine), in the hygienic evaluation the registered mean values of maximum vibration acceleration should be considered (0.82-1.00 m/s^2), which for six months (April, May, June, August, September and October) exceed the quoted standard. This is confirmed by the data from literature, which evidence the hazardous effect of whole body vibration on the musculoskeletal system. Barbieri et al. [11], Bovenzi and Betta [19], Boshuizen et al. [13], Palmer et al. [16] and Manninen et al. [21] observed a considerably more frequent occurrence of back pain in tractor operators than in the control group not exposed to whole body vibration. The frequency of occurrence of this pain increased with the vibration dose absorbed. According to Bovenzi and Betta [19], occupational exposure to whole body vibration is accompanied by an increased risk of back pain in the lumbar region, ischias and degenerative changes in the spine, including deformation of lumbar intervertebral discs.

The mean values of vibration accelerations obtained in the presented study exceeded the *daily exposure action values* ($A(8)_w$ = 0.5 m/s^2) in August and April (0.56-0.60 m/s^2), and remained on the allowable value limit in September. The exceeding of the allowable value limit with respect to the mean maximum acceleration values concerned almost all months of the year, except January, February and December.

Considering *daily exposure action values,* Directive 2002/44/EC of the European Parliament [33] specifies the duties of employers in the area of protection of employees against risk, which results or may result from exposure to mechanical vibration at work. The Directive obliges the employer to perform the evaluation of risk and, when needed, to perform measurements of the level of mechanical vibration to which workers are exposed. Taking into consideration technical progress and availability of the means of risk control at the site of its occurrence, the employer should eliminate this risk at its source or limit it to a minimum. When *daily exposure action values* are exceeded, the employer is obliged to establish and implement in practice the programme of technical and/or organizational means aimed at the limitation to a minimum of exposure to vibration, with consideration of the following:

– other methods of work and selection of adequate working equipment, which would cause lower exposure;
– equipment which limits whole body vibration (e.g. shock absorbing seats);
– programmes for the maintenance of working equipment, workplaces;
– information and training of employees in the area of safe use of working equipment;
– proper working time schedules, with breaks for rest.

CONCLUSIONS

1. The studies of annual exposure to whole body mechanical vibration among private farmers specializing in mixed production confirmed that the degree of mechanical vibration load is conditioned by both the level of vibration transmitted from the seats of vehicles to the whole body of an operator, and the duration of exposure to this factor within a specified time interval.
2. The studies showed that the highest values of the total vibration dose (d) occurred in April and August.
3. The calculated mean daily exposure to vibration showed the highest values during four months of the year: April, August, September and October (0.49-0.60 m/s^2). The average value of this parameter for the whole year reached the level of 0.44 m/s^2 (remained below allowable values).
4. Considering the occurrence of mechanical shocks in agricultural vehicles (high, standard exceeding maximum acceleration values were registered within the range 0.82-1.00 m/s^2), and exceeding the *daily exposure action value*, proper steps should be undertaken with respect to the protection of private farmers against risk resulting from exposure to mechanical vibration while performing work activities.

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