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# Risk exposure to vibration and noise in the use of agricultural track-laying tractors

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## Abstract

Human exposure to mechanical vibration may represent a significant risk factor for exposed workers in the agricultural sector. Also, noise in agriculture is one of the risk factors to be taken into account in the evaluation of workers' health and safety. One of the major sources of discomfort for the workers operating a tractors is the noise to which they are exposed during work. The aim of this study was to evaluate the risk of exposure to whole-body vibration for the operator driving track-laying tractors in vineyard orchard and the noise level. The experimental tests were performed with six different track-laying tractors coupled with the same rototilling machine. The results showed that the vibration values of track-laying tractors coupled to rototilling machine, referred to the 8-hour working day, were always higher than 0.5 m s$^{-2}$, the daily exposure action value established by Directive 2002/44/EC of the European Parliament. The daily noise exposure levels always exceeded the exposure limit value of 87 dB(A) established by Directive 2003/10/EC of the European Parliament. The ANOVA repeated measures model showed that the factor 'site', namely, the soil characteristics, did not influence the vibration level on the X and Y-axes of the tractors measured, regardless of their age. In the Z-axis, the vibration level was enhanced as the soil structure increased. As tractor age increased, the influence of soil characteristics was less important. In term of the age of the tractor and the number of hours worked, it was possible to identify three risk classes, which were up to 3,000 hours worked and offered a low risk; from 3,000 – 6,000 hours worked with a medium risk, and over 6,000 hours with a high risk level.

## Key words

noise, safety, track-laying tractor, whole body vibration

## INTRODUCTION

Human exposure to mechanical vibration may represent a significant risk factor for exposed workers in the agricultural sector, with particular reference to the operators driving tractors [1, 2, 3]. The growing relevance of this risk in Europe, especially in the industrialized countries, both in terms of health risk and economic damage, led to the drafting of regulations and specific measures to reduce it. European Directive 2002/44/EC [4] – 'on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (vibration)' – was the key step to ensure the implementation of specific protection measures for the prevention of risk exposure to vibration in the workplace.

Whole Body Vibration (WBV) is one of the most commonly investigated ergonomic factors affecting both agricultural operators' health and work efficiency. Many studies have been carried out to evaluate WBV for agricultural wheel tractor drivers [5, 6, 7], whereas very few studies have concern track-laying tractors [8]. Track-laying tractors are not as prevalent as wheel tractors. However, in countries like Italy, Spain, France and in vineyards and orchards areas with soil slope ranging from 20–30%, they are widespread because they allow the obtaining of more benefits than wheel tractors. Worldwide, an interest of 15% of the total market for tractors concerns track-laying tractors that seem to be irreplaceable for certain environments and for some crops. Their advantages are manifold and include a guaranteed high stability in driving due to the low center of gravity, and the large surface on which the weight of the machine is uniformly distributed, and ease of maneuvering in confined spaces, due to the compactness of the tractor and the ability to block one of the tracks to effect a spin and make a full turn of 360 degrees, and the higher gripping ability of the tracks, in contrast to tyres, which limits slips and allows high tractive efforts.

By contrast, the reasons that oppose the spread of track-laying tractors are to be found in slow transfers, due to the low travel speed (up to 15 km/h), need to mount the shoes on the tracks to avoid damage to the road surface, and lower driving comfort, due to the intrinsic design features which do not allow the partial absorption of vibration and shocks transmitted from the ground which is exerted by the tyres in wheeled tractors [9].

Noise in agriculture is another relevant risk factor to be taken into account in evaluating health and safety of workers. In fact, one of the major sources of discomfort for workers operating a tractor is the noise that occurs during work [10, 11, 12, 13, 14, 15]. Moreover, excessive noise is a global occupational health hazard with considerable social and physiological impacts, including noise-induced hearing loss (NIHL) [16].

Directive 2003/10/EC of the European Parliament [17] was enacted on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (noise). It stipulates an average upper limit

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of noise exposure of a worker during an eight-hour shift of work at 85 dB(A). This level is supposed to inhibit hearing impairments of workers [18]. Even the ILO (International Labour Organization) gives this indication in its code of practice [19].

## OBJECTIVE

The aim of this study is to evaluate the influence of tractor age and soil characteristics on whole body vibration (WBV) and noise risk in the use of track-laying tractors. Six tractors with different ages were tested during field operations in a vineyard; three test sites were considered, differing in soil characteristics.

The results of this study could offer useful instructions for users of machines and equipment that may result in exposure to vibrations and noise risk within the agricultural sector in order to be in line with the provisions of the regulations on safety in the workplace.

## MATERIALS AND METHOD

**Test sites.** The tests were carried out on three farms located in Sicily, southern Italy, coded A, B and C, in 10-year vineyard plots trained with the hedgerow system, carried out in April and May 2014, at the same soil moisture status. The operator driving the tractor was the same, since it is known that exposure to WBV can be dependent on the driver body mass [2]. Six homogeneous plots of a vineyard, each on a flat plot about 200 m long, were identified at the three test sites in order to test six different track-laying tractors coupled to the same rototilling machine.

**Test site A.** Located in the province of Trapani, 150 m above sea level. Soil characteristics: Lithosols (Lithic Rhodoxeralfs) with a sandy texture without skeleton.

**Test site B.** Located in the province of Agrigento, 180 m above sea level. The soil belonged to Regosols (Typic Xerorthents), clay texture with no skeleton.

**Test site C.** Located in the province of Palermo, 280 m above sea level. The soil characteristics: Vertisols (Vertic Xerorthents), clay texture without the skeleton.

**Machines used in the tests.** The track-laying tractors used during the tests were designed and produced by world-renowned companies and had been in use for 2–12 years (Tab. 1) and had the same mass (3,800 kg), power (58 kW) and wheel track (1,650 mm).

**Table 1.** Main technical characteristics of tractors used in the tests

| Tractor | Manifacturer | Registration year | Hours of work [n] |
|---|---|---|---|
| T1 | New Holland | 2012 | 2,000 |
| T2 | Lamborghini | 2010 | 3,000 |
| T3 | New Holland | 2008 | 4,000 |
| T4 | Landini | 2006 | 5,000 |
| T5 | New Holland | 2004 | 6,000 |
| T6 | New Holland | 2002 | 7,500 |

All the tractors were equipped with a driving platform suspended on a silent block, the seats were anatomically shaped (400 mm width, 410 mm depth, 390 mm height) with arm rests, equipped with suspension and shock absorbers, adjustable according to the driver's weight.

Table 2 shows the main characteristics of the rototilling machine coupled with the six tractors considered.

**Table 2.** Main technical characteristics of the rototilling machines used in the tests

| Mass [kg] | Width [m] | Length [m] | Tillage depth [m] | Working tools [n] |
|---|---|---|---|---|
| 450 | 1.80 | 0.5 | 0.12 | 36 |

The rototilling machine is commonly used with the track-laying tractor, especially in difficult environments characterized by steep slopes, clay soils, and orchards. In one step it allows cleaning of the soil from weeds, crumbling of the topsoil and its preparation for the subsequent operations. It can be adjusted to enhance the tractor coupling and optimize the balance between energy cost and quality of work [20, 21].

**Instruments used for the tests – Vibration measurements.** A triaxial piezoelectric accelerometer, signal conditioner, digital archiving system, frequency analyzer, connecting cables and a calibrator were used for the vibration measurements. The tests were performed according to ISO 2631-1, 2008 [22]. This defines standardized methods of measuring whole body vibration and provides some guidelines for the assessment of health effects. The frequency spectrum and the direction and intensity of the acceleration were taken into account for the assessment of exposure to whole-body vibration.

Regulation ISO 2631-1:2008 defines the coordinate systems for accelerations measurement according to the entry point of the vibrations, while keeping the axes x, y and z always in the same direction but with different origin according to the operator›s position. In whole-body vibration, the z (vertical) axis is directed in the direction of the spinal column and this direction is the most dangerous for the drivers. Acceleration levels were measured as frequency-weighted root mean square values, in the frequency range of 0.5–80 Hz. The measurements were made by inserting the triaxial accelerometer between the seat and the operator. The portable vibration analyzer HD2070 (Delta Ohm, Padua, Italy), was used during the tests (Fig. 1). It is able to perform spectral analysis and statistics simultaneously on three channels.

**Figure 1.** Triaxial accelerometer with adapter for the driving seat to measure whole-body vibrations

The mean square frequency-weighted acceleration [m s$^{-2}$] was evaluated along each of the three axial components of the acceleration vector ($a_{wx}$, $a_{wy}$, $a_{wz}$):

$$a_w = \left[\frac{1}{T}\int_0^T a_w^2(t)dt\right]^{1/2} \quad (1)$$

The total vibration value to which the body is exposed ($a_v$) was determined by the following relationship:

$$a_v = (k_x^2\, a_{wx}^2 + k_y^2\, a_{wy}^2 + k_z^2\, a_{wz}^2)^{1/2} \quad (2)$$

where $k_x = k_y = 1.4$ and $k_z = 1$.

Acceleration data were correlated with the actual time of exposure in order to calculate the vibration risk assessment A(8) as the daily exposure value standardized to an eight-hour reference period (Article 3 of Directive 2002/44/EC):

$$A(8) = a_v\sqrt{\frac{T_e}{8}} \quad (3)$$

where Te is the total daily duration of vibration exposure (hours) that was assumed to be 6.5 hours.

**Noise measurements.** The instrument used in the tests is a precision integrating portable sound level meter, model HD2110L (Delta OHM, Padua, Italy) (Fig. 2). The instrument complies with class 1 specifications of IEC 61672–1, IEC 60651 and IEC 60804. The constant percentage bandwidth filters are compliant with class 0, IEC 61260 specifications, and the microphone with IEC 61094–4.

**Figure 2.** HD2110L integrating portable sound level meter (Delta OHM, Padua, Italy.

The tests were performed in compliance with EN ISO 9612 regulation [23]. The weighted time-averaged sound pressure level ($L_{Aeq}$) and C-weighted peak sound pressure level ($L_{Cpk}$) were measured.

According to article 3 of Directive 2003/10/EC of the European Parliament, the exposure limit values and exposure action values in respect of the daily noise exposure levels and peak sound pressure are fixed at:

- lower exposure action values: $L_{EX,8h}$ = 80 dB(A) $p_{peak}$ = 135 dB(C);
- upper exposure action values: $L_{EX,8h}$ = 85 dB(A) $p_{peak}$ = 137 dB(C);
- exposure limit values: $L_{EX,8h}$ = 87 dB(A) $p_{peak}$ = 140 dB(C);

where $L_{Eex,8h}$ values (occupational noise) is reported for 8 working hours.

$L_{Eex,8h}$ value is given by the following equation:

$$L_{EX,8h} = L_{Aeq,Te} + 10 \log (T_e / T_0)$$

where Te is the effective duration, in hours, of the working day and $T_0$ is the reference duration equal to 8 hours. In this case, Te was assumed to be 6.5 hours.

During the measurements, the microphone was placed near the driver's ear at a distance of at least 0.1 m from the entrance of the external ear canal, approximately 0.04 m above the shoulder. Each measurement had a duration of 2 minutes (the case of stationary noise source) and the parameters were analyzed at intervals of 0.5 seconds. Before each series of measurements, the instrument calibration was performed applying a sound calibrator. The collected data were downloaded to the PC for processing.

**Statistical analysis.** An ANOVA repeated measures model was applied to the data. This is a statistical approach to repeated measure designs. One of the underlying assumptions for the F tests in ANOVA is independence of observations. In a repeated-measures design, this assumption is almost certainly violated. In a repeated-measures ANOVA, the experimental units are observed for each level of one or more of the other categorical variables in the model.

A correction to the degrees of freedom of the F test was used for the lack of independence for those terms in the model which involved repeated measures. Three corrections methods were considered: Box's method [24], according to Milliken and Johnson [25], as Box's conservative correction factor while Winer et al. [26] called it simply the conservative correction factor; Greenhouse-Geisser [27] provided an estimate for the correction factor, this value was estimated from the data. Huynh and Feldt [28] showed that the Greenhouse–Geisser tends to be conservatively biased. They provided a revised correction factor denoted the Huynh–Feldt epsilon. When the Huynh–Feldt epsilon exceeds 1, it is set to 1. To this consideration a natural ordering for these correction factors is as follows: Box's conservative epsilon<Greenhouse–Geisser epsilon< Huynh–Feldt epsilon< 1.

In a repeated measures design, variability can be decomposed into two parts: the between-treatments variability (or within-subjects effects, excluding individual differences) and within-treatments variability. Additionally, the within-treatments variability can be viewed as sum of the between-subjects variability (individual differences) and error (excluding the individual differences). When the epsilon correction is equal to 1, no correction is necessary.

## RESULTS AND DISCUSSION

**Whole Body Vibration measurements.** On the basis of the factorial design, the existence of significant effects were tested among tractors and the correlation between repeated observations for each level of the variable axis were taken into account, namely, X, Y and Z-axes. The values measured during the tests are shown in Table 3 for the three axes and the three sites considered. The acceleration values obtained were comparable with those obtained in [8], but higher than those recorded to wheel tractors in [7], with mean $a_{wz}$ values between 0.28 – 0.40 m s$^{-2}$, depending on forward speed and tyre type.

**Table 3.** Components of the acceleration vectors ($a_{wx}$, $a_{wy}$, $a_{wz}$) along X, Y and Z-axes for the three test sites (A, B and C). Each trial was performed in triplicate

| Tractor acceleration [m s$^{-2}$] | | Replications and site | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 |
| | | A | B | C | A | B | C | A | B | C |
| $a_{wx}$ | T1 | 0.32 | 0.37 | 0.32 | 0.45 | 0.37 | 0.39 | 0.38 | 0.42 | 0.41 |
| | T2 | 0.38 | 0.46 | 0.31 | 0.37 | 0.34 | 0.36 | 0.43 | 0.38 | 0.41 |
| | T3 | 0.30 | 0.45 | 0.44 | 0.35 | 0.40 | 0.45 | 0.40 | 0.35 | 0.35 |
| | T4 | 0.40 | 0.59 | 0.41 | 0.49 | 0.42 | 0.44 | 0.53 | 0.39 | 0.51 |
| | T5 | 0.57 | 0.67 | 0.58 | 0.49 | 0.50 | 0.49 | 0.57 | 0.55 | 0.55 |
| | T6 | 0.65 | 0.69 | 0.69 | 0.69 | 0.51 | 0.63 | 0.58 | 0.62 | 0.65 |
| $a_{wy}$ | T1 | 0.38 | 0.35 | 0.34 | 0.36 | 0.45 | 0.22 | 0.35 | 0.40 | 0.26 |
| | T2 | 0.28 | 0.46 | 0.36 | 0.30 | 0.32 | 0.32 | 0.28 | 0.36 | 0.28 |
| | T3 | 0.24 | 0.41 | 0.43 | 0.30 | 0.32 | 0.36 | 0.28 | 0.33 | 0.37 |
| | T4 | 0.36 | 0.45 | 0.49 | 0.38 | 0.32 | 0.41 | 0.37 | 0.38 | 0.42 |
| | T5 | 0.42 | 0.43 | 0.42 | 0.39 | 0.39 | 0.38 | 0.38 | 0.42 | 0.42 |
| | T6 | 0.40 | 0.56 | 0.52 | 0.44 | 0.40 | 0.48 | 0.42 | 0.39 | 0.43 |
| $a_{wz}$ | T1 | 0.65 | 0.82 | 0.89 | 0.6 | 0.74 | 0.82 | 0.65 | 0.64 | 0.85 |
| | T2 | 0.64 | 0.85 | 0.93 | 0.62 | 0.74 | 0.88 | 0.64 | 0.85 | 0.82 |
| | T3 | 0.84 | 0.92 | 0.99 | 0.73 | 0.86 | 0.92 | 0.77 | 0.76 | 0.85 |
| | T4 | 0.82 | 0.97 | 1.02 | 0.79 | 0.89 | 0.95 | 0.82 | 0.86 | 0.90 |
| | T5 | 0.9 | 0.99 | 1.10 | 0.92 | 0.95 | 0.92 | 0.83 | 0.88 | 0.95 |
| | T6 | 1.00 | 1.06 | 1.21 | 0.96 | 1.01 | 1.12 | 0.97 | 1.08 | 1.12 |

The existence of significant effects of the factors 'axis', 'tractor' and 'site' and the site-axis interaction significance for each tractor were evaluated. Axis, site and tractor were fixed factors, replications were treated as random. Both the axis, tractor and site, and the interaction between site and tractor were tested with the tractor nested within the axis. The axis was considered as a repeated variable because each tractors was measured in the three axes in triplicate.

The repeated ANOVA model showed the significance of all the effects (Tab. 4). The within subject variability can be decomposed as the sum of the variance between subject and the error term between replications. The F test correction for repeated measures with the three tests confirmed the high significance of the axis effect, but brought the axis-site interaction significance nested in the levels of tractors to about 9%.

The predicted values and confidence intervals of the vibrations transmitted by the six tractors for the effects of interaction between axes, tractors and sites are shown in Figure 3a. The factor 'site', namely, the soil characteristics, did not influence the vibration level on the X and Y-axes in the six tractors, regardless of their age. A different behaviour was obtained for the Z-axis where the vibration level was enhanced as the soil structure increased. Moreover, T1 and T2 significantly differed among the three test sites, showing the considerable role of the tractor age in the vibration levels affecting the spine of the operator. As tractor age increases, the influence of soil characteristics is less important.

Looking only at the marginal axis-site effect (Fig. 3b), the vibration measures on the Z-axis significantly differed in the diverse soil types, while X and Y-axes vibration levels did not differ in the three sites. Regarding the behavior of each tractor (Fig. 3c), statistically significant differences were found in the X-axis vibration values between T6 and the other tractors at all the test sites, but Z-axis showed the most important significant variations at the different test sites. A greater distance existed between T5 and T6. The vibration level increased with tractor age, so that it was possible to identify three tractor groups: T1-T2; T3-T4-T5; T6. As a consequence, three thresholds of differentiation in the behavior of the tractor valid for the three sites can be indicated: 1) under 3,000, 2) between 3,000 – 6,000, 3) over 6,000 hours of work characterizing the vibration level that a track-laying tractor transmitted to the operator. The same results shown in Fig. 3d highlight the axis effect hiding the

**Table 4.** Results of ANOVA repeated measures model on the acceleration vector ($a_{wx}$, $a_{wy}$, $a_{wz}$) along X, Y and Z-axes

| Source | Partial SS | Df | MS | F | Prob>F |
|---|---|---|---|---|---|
| Model | 9.367 | 89 | 0.105 | 50.47 | 0 |
| Between -treatments variability | | | | | |
| Axis | 7.603 | 2 | 3.802 | 1823.15 | 0 |
| Tractor | 1.052 | 5 | 0.21 | 43.82 | 0 |
| Site | 0.135 | 2 | 0.068 | 32.48 | 0 |
| Tractor\|Axis-Site | 0.39 | 44 | 0.009 | 1.86 | 0.029 |
| Within treatment variability | | | | | |
| – Between subject replications | 0.172 | 36 | 0.005 | 2.29 | 0.001 |
| – Error between subject term | 0.172 | 36 | 0.005 | | |
| Residual | 0.15 | 72 | 0.002 | | |
| Total | 9.517 | 161 | 0.059 | | |
| N=162 R-squared=0.98 | | | | | |

| Within treatment correction | df | F | Regular | H-F | G-G | Box |
|---|---|---|---|---|---|---|
| Axis | 2 | 796.61 | 0 | 0 | 0 | 0 |
| Tractors\|Axis-Site | 44 | 1.86 | 0.0293 | 0.0293 | 0.036 | 0.0931 |
| Replications in Site and Tractor | 36 | | | | | |
| Huynh-Feldt epsilon = 1.4028 reset to 1.0000 | | | | | | |
| Greenhouse-Geisser epsilon = 0.9066 | | | | | | |
| Box's conservative epsilon = 0.5000 | | | | | | |

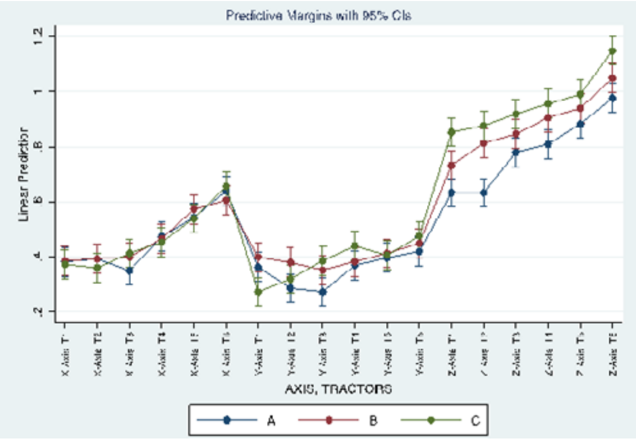

**Figure 3a.** Predicted margins of axis-tractor interaction

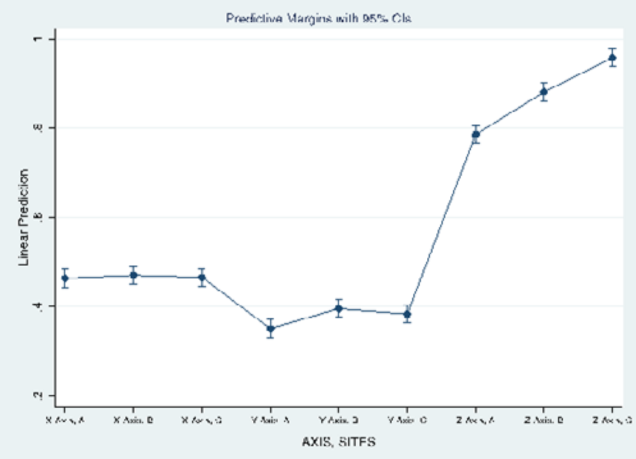

**Figure 3b.** Predicted vibration levels in axes and sites

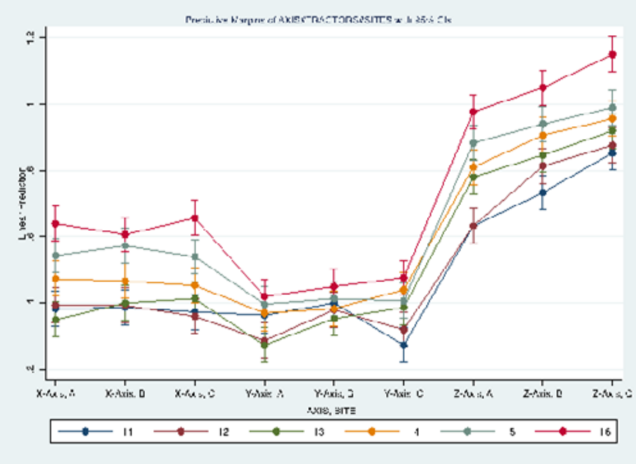

**Figure 3c.** Predicted margins of axis-site interaction

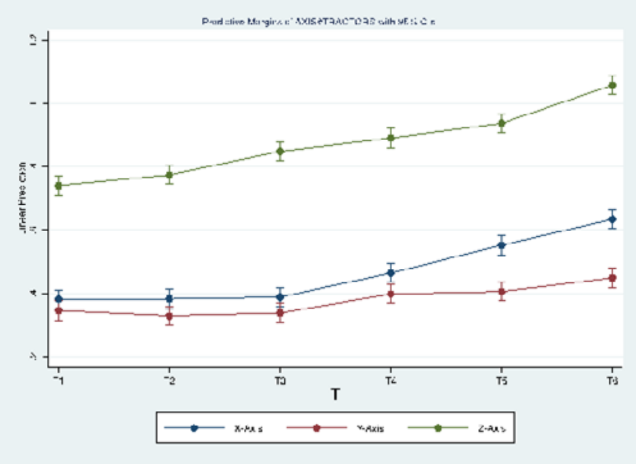

**Figure 3d.** Predicted vibration levels for tractor.

site effect. In the three axes, the vibration levels increase from T1 – T6, i.e. with the level of use of the tractor, and the Z-axes showing the highest values. Statistically significant differences were found between T6 and the other tractors in the Z-axis.

The total vibration values, i.e. the acceleration vector sum $a_v$ evaluated according to [2], were studied using an ANOVA repeated measures model in which 'tractor', 'site' and their interaction were considered as fixed factors, while the repeated measures in each site were treated as a random variable. A significant effect for 'tractor' was obtained, while the 'site-tractor' interaction was not significant (p=0.93). The error correction for repeated measures confirmed the significance for 'tractor' and the non-significance of the interaction effect (Tab. 5). Considering the acceleration vector sum $a_v$, the vibration level on the single axis was hidden, while it varied with the tractor and the soil type. Therefore, the overall indicator $a_v$ produced a flattening in the level of vibration for the single axis and caused no significant effects in the site-tractor interaction, which is contrary to that obtained when considering analysis for the different axes nested in the tractors.

**Table 5.** Results of ANOVA repeated measures model on the acceleration vector sum $a_v$

No. of obs = 54, R-squared = 0.94

| Source | Partial SS | df | MS | F | Prob>F |
|---|---|---|---|---|---|
| Model | 1.962 | 29 | 0.068 | 12.67 | 0 |
| *Between -treatments variability* | | | | | |
| Tractor | 1.592 | 5 | 0.318 | 29.17 | 0 |
| Site | 0.198 | 2 | 0.099 | 9.06 | 0.004 |
| Site-Tractor | 0.042 | 10 | 0.004 | 0.38 | 0.931 |
| *Within Treatment variability replications* | 0.131 | 12 | 0.011 | 2.04 | 0.066 |
| *Error between subject term replications* | 0.131 | 12 | 0.011 | | |
| Residual | 0.128 | 24 | 0.005 | | |
| **Total** | **2.090** | **53** | **0.039** | | |

*Correction of F test between-subjects effect*

| Source | df | F | Regular | H-F | G-G | Box |
|---|---|---|---|---|---|---|
| Site | 2 | 9.06 | 0.004 | 0.004 | 0.0121 | 0.0237 |
| Site#Tractor | 10 | 0.38 | 0.9312 | 0.9312 | 0.8869 | 0.8445 |
| Replications | 12 | | | | | |

Huynh-Feldt epsilon = 1.0686 reset to 1
Greenhouse-Geisser epsilon=0.6864
Box's conservative epsilon =0.5

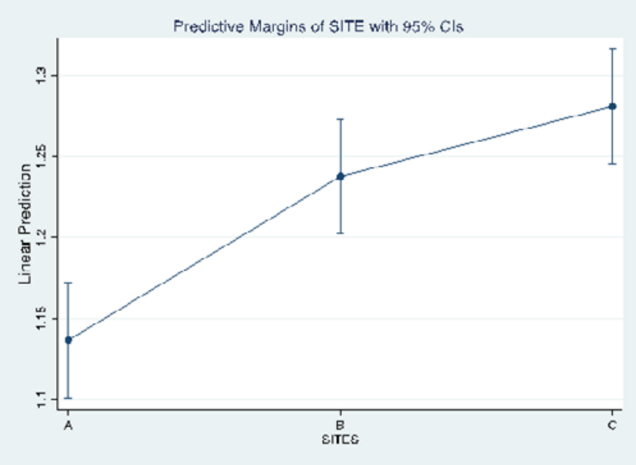

**Figure 4.** Predictive margin of site

The overall effect of the site is shown in Figure 4, where statistically significant differences appeared between site A and sites B and C. It could be concluded that site A presented a low vibration risk, unlike sites B and C that can be associated to a higher vibration risk.

Scarlett et al. [3] also evaluated WBV exposure levels during farm operations with 90–130 kW four-wheel-drive tractors with values very dependent upon the nature of field operations ranging from 0.5 (spraying) – 1.2 m s$^{-2}$ (cultivating). Servadio and Belfiore obtained considerably lower $a_v$ values (0.44–0.54 m s$^{-2}$) for a wheel tractor of medium power on a conglomerate bituminous closed track with different tires and forward speed [29].

In the presented tests, the daily vibration exposure values A(8) measured on the driver's seat of the six tractors in test sites A, B and C showed that all the tractors exceeded the daily exposure action value of 0.5 m s$^{-2}$ (yellow line) established by Directive 2002/44/EC of the European Parliament, and tractors T5 and T6 even exceeded the daily exposure limit value of 1.15 m s$^{-2}$ (red line), regardless of the soil type. Pessina et al. [8] obtained similar results for 75 kW powered track-laying tractors coupled with a ripper on clay soils.

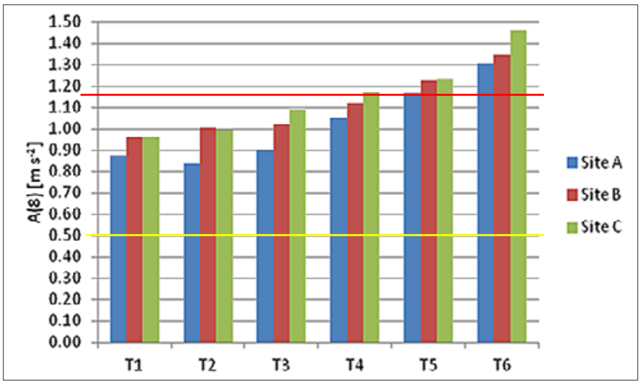

**Figure 5.** Daily vibration exposure value A(8) measured on the driver's seat of the six tractors in test sites A, B and C. Yellow and red lines, respectively, represent the action and limit values according to Directive 2002/44/EC of the European Parliament

**Noise level measurements.** Noise level measurements (Tab. 6) were evaluated with a repeated-measures model considering the six tractors and the three sites. Three repeated measures on each tractor were performed nested within the three sites. Sites were treated as random variables.

**Table 6.** A-weighted time-averaged sound pressure levels (LAeq) at test sites A, B and C for the six tractors (T1-T6). Each trial was performed in triplicate

| | Replications and Site | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | ------------ 1 ------------ | | | ------------ 2 ------------ | | | ------------ 3 ------------ | | |
| **Tractor** | A | B | C | A | B | C | A | B | C |
| T1 | 90.15 | 91.95 | 95 | 91.11 | 92.96 | 95.01 | 89.69 | 92.78 | 93.86 |
| T2 | 92.34 | 93.94 | 96 | 91.65 | 93.35 | 95.8 | 90.38 | 93.96 | 94.46 |
| T3 | 92.75 | 94.02 | 95.8 | 92.08 | 94.9 | 95.23 | 91.61 | 94.54 | 95.48 |
| T4 | 93.35 | 95.28 | 97.5 | 93.02 | 95.99 | 96.5 | 92.65 | 94.96 | 97.3 |
| T5 | 92.75 | 95.28 | 97.86 | 93.68 | 95.29 | 97.59 | 93.21 | 95.75 | 96.56 |
| T6 | 95.74 | 97.78 | 99.02 | 94.95 | 98.55 | 98.99 | 96.18 | 97.65 | 99.68 |

Noise pressure mean values show a minimum of 90.15 dB(A) obtained by tractor T1 at test site A, and a maximum of 99.68 dB(A) for tractor T6 in test site C (Tab. 6). The upper action value of 85 dB(A), lower action value (equal to 80 dB(A)) and exposure limit value (equal to 87 dB(A)) established by article 3 of Directive 2003/10/EC were always exceeded. With reference to C-weighted peak sound pressure levels (LCpk), neither the exposure limit value equal to 140 dB(C), or the upper and lower action values (equal to 137 dB(C) and 135 dB(C)) were reached or exceeded by any of the tested machines (data not shown). Aybek et al. [10] measured the sound pressure levels of wheel tractors without a cabin, with a field-installed cabin and original cabin, and, of course, obtained the highest values for tractors without a cabin, equal to 89 dB(A) for rotary tiller operation; therefore, lower than the values obtained in the presented trials for track-laying tractors. Similar results were obtained [13] with the use of a wheel tractor in pulling a trailer on an asphalt road. Conversely, exposure levels of noise perceived by the operators driving wheeled tractors with a cabin lower than 85 dB(A), the upper exposure action value, were obtained by Bilski [11]. However, considerable infrasonic noise levels were found [11] and are worthy of further study with reference to track-laying tractors.

No studies were found on the evaluation of noise levels of agricultural tractors as a function of soil type and age of the tractor.

**Table 7.** Results of ANOVA repeated measures model for noise levels

| Source | | Partial SS | Df | MS | F | Prob>F |
|---|---|---|---|---|---|---|
| Model | | 286.167 | 29 | 9.868 | 31.2 | 0 |
| Between -treatments variability | | | | | | |
| Tractor | | 141.518 | 5 | 28.304 | 81.28 | 0 |
| Site | | 139.024 | 2 | 69.512 | 219.8 | 0 |
| Site#Ttactor | | 1.447 | 10 | 0.145 | 0.46 | 0.901 |
| Within treatment variability | | | | | | |
| Error between subject term | | 4.179 | 12 | 0.348 | | |
| Residual | | 7.590 | 24 | 0.316 | | |
| Total | | 293.757 | 53 | 5.543 | | |
| F-correction | df | F | Regular | H-F | G-G | Box |
| Site | 2 | 219.81 | 0 | 0 | 0 | 0 |
| Site#Tractor | 10 | 0.46 | 0.901 | 0.901 | 0.867 | 0.800 |
| Residual | 24 | | | | | |

The repeated-measure epsilon corrections were applied to any terms tested in the main ANOVA Table that had the repeated variable in the term (Tab. 7). The results of ANOVA showed that 'site' had a significant influence. The interaction between 'tractor' and 'site' was not significant (p=0.901), which affirms that change of soil type and noise level of a given tractor does not vary. The difference in the noise level is explained by the type of soil and the tractor's state of use. The repeated-measure epsilon corrections did not change these conclusions.

The noise level increased with the age of the tractor (Fig. 6), ranging from T1 – T6, but the distance between T5 and T6 was higher than the others. Concerning the different test sites, the noise level increased as the soil texture became stronger.

## CONCLUSIONS

The study was carried out in order to assess WBV and noise levels transmitted to the operator driving track-laying tractors during rototilling operations in a vineyard. The experimental tests were performed at three test sites which varied in soil texture, and with six track-laying tractors that

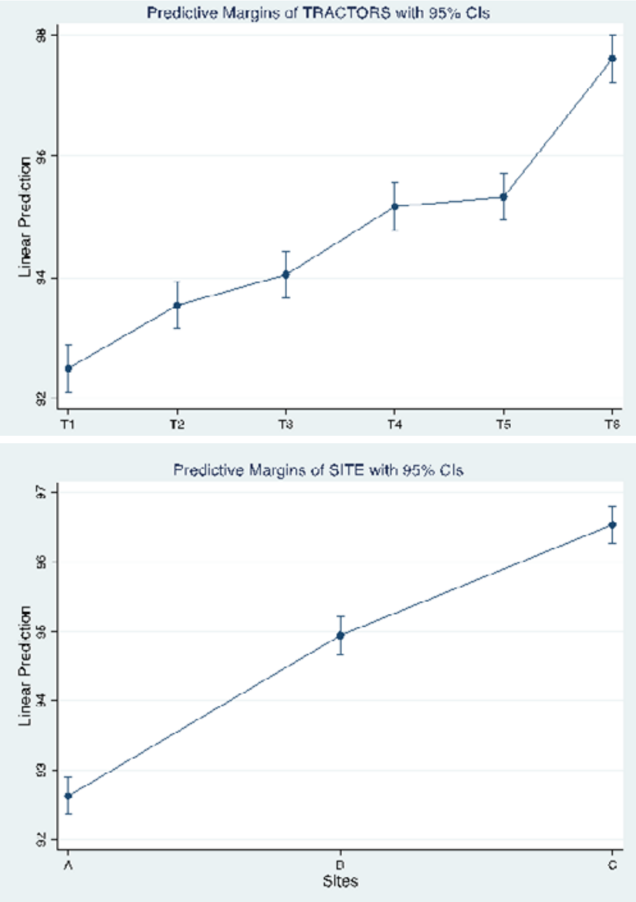

**Figure 6.** Marginal predictions of noise by tractors and sites.

differed in the number of hours worked. The findings of this study can be summarized as follows.

On the basis of the soil type, it was possible to identify two risk classes for WBV considering the site effect. Site A – Lithosols (Lithic Rhodoxeralfs) had a low risk site B – Regosols (Typic Xerorthents) and site C – Vertisols (Vertic Xerorthents), were characterized by high risk.

In term of the age of the tractor and number of hours worked, it was possible to identify three risk classes: up to 3,000 hours worked and offered a low risk, 3,000 – 6,000 hours worked with medium risk, and over 6,000 hours with a high risk level.

Related to the axis effect, the Z-axis showed very different behaviour with respect to X and Y-axes that was hidden in considering the acceleration vector sum $a_v$.

To overcome the adverse noise levels, the use is mandatory of means of personal protection, such as earplugs to insulate noise on track-laying tractors without a cabin.

It is suggested that legislators take into account the soil type and the number of hours worked by the tractor as key factors in the evaluation of WBV and noise levels for track-laying tractors.

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