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What Is the Current Ergonomic Condition of Chainsaws in Non-Professional Use? A Case Study to Determine Vibrations and Noises in Small-Scale Agroforestry Farms

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Abstract: Agroforestry or agricultural forestry is an important resource for the exploitation of wood resources commonly based on a low level of mechanization and integrating agriculture crops land-management. Agroforestry areas consist often of buffer strip forest along the farms' boundaries or on small forest stands within the same farms. Felling is commonly based on the use of chainsaws which are used occasionally, and are often aged models and with little maintenance done on them. In this context, the present study analyzes the vibration and noise generated by chainsaws in the specific contest of the agroforestry farms. The aim is to verify the hand-arm vibrations and noise level, which self-employed agroforest operators are exposed with the occasional use of aged and rarely maintained chainsaws. The main results show that vibration exposures are significantly affected by the model and condition of use of the chainsaw and at lower level, but still significant, by the wood and the position of the handle. Regarding noise levels, the chainsaw model and condition of use also has significant effects. In summary, this study highlights that the importance of the condition of use of the chainsaw has an important effect on the vibrations and noise exposition and that these, although limited due to the limited daily use by operators, must be carefully taken into consideration, and provide for containment actions through adequate information and training.

Keywords: noise; vibration; small-scale; mechanization; forest operations; softwood; hardwood

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1. Introduction

In rural areas, small-scale agroforestry is widely recognized for increasing and diversifying farm productivity while releasing pressure on existing forests. As a consequence, agroforestry or agriculture forestry represents an important local wood resource exploitation in rural areas in which wood harvesting is commonly based on semi-mechanized harvesting system. This can be described generally as a labor-intensive, low-input land-use approach, employing man-power or draft animals harvesting system, rather than machine-intensive harvesting system based on full-mechanized approach [1,2]. In agroforestry practices, the advantage consists of growing even of high economic value with low energy and management inputs compared to industrial forest plantations.

Different tree species may be present in form of scattered trees, along contours, on farm boundaries, or established as rotational woodlots or blocks [3–5]. Such trees are managed in combination with crops in agroforestry systems and serve a number of ecological and economic functions that are partly similar to those of trees in forests, although different in extent [6,7].

Focusing on the harvesting operation, most of the agroforestry stands are normally managed by the same self-employed owners and commonly the motor manual felling is the unique process used. Even if occasionally, the use of the chainsaw in agroforestry system can take place intensively and consequently for periods ranging from a couple of days to a couple of weeks per year. This depends on the intensity and the extension of the wood exploitation and on the planning of the farm activities. As a consequence, farmers can be exposed to vibration and noise risks, even if occasionally by pushing the chainsaw to the maximum engine power. Its application presents a threat to workers' safety and health.

This condition is even more accentuated in the circumstance of using aged chainsaws and with a lack of maintenance and thus the larger exposure to vibration and noise. As the activity of wood harvesting is irregular and not constant over the years, accident prevention studies aimed at small-scale agroforestry work have been limited [8]. However, as it is reported recently by FAO [9], agroforestry-related work is among the most hazardous of all non-military activities. In this context, vibrations and noise risks are underestimated by farmers, as they do not pose an immediate risk to human health. It is well known that the consequences of exposure to noise and vibrations can be very serious [10], but the symptoms of the disease can appear several years after the exposure. Occupational noise [11] is defined as sound pressure perceived by the human ear as an undesirable sound with different frequencies, intensities, and phases [12]. According to EU Directive 2003/10/EC [13], the noise maximum exposure threshold is equal to 87 dB(A) considered as the time-weighted average value of noise exposure levels for a nominal eight-hour working day. Exposure to noise is an important and preventable cause of hearing loss [14], and can be caused by short exposures to extremely high sound levels or by repeated exposures to moderate levels [15]. High-intensity sound can negatively affect hearing capability with a temporary or permanent loss of sensitivity and acuity [16–18].

When working with chainsaws, loads on hands and arms caused by vibrations can exceed the daily exposures action value [19–21]. The vibrations, considered to be short, rapid, and irregular shaking movements, and expressed by EU Directive 2002/44/EC [19] as frequency weighted acceleration, have a daily exposure action value set of 2.5 m s^{-2} and a daily exposure limit value of 5 m s^{-2}.

According to previous research [21,22], the vibration level of the chainsaw is affected by a large number of parameters (worker, chain tension, bar length, fuel quantity in the tank, method of holding the saw). The firm grip of the chainsaw handle, affecting the transfer of hand-arm vibrations, depends on the worker's experience, work operations and wood hardness [23]. The consequences related to exposure of workers to vibrations have been extensively studied in the literature, noting numbness of the hands and arms or tingling in the fingers and deterioration of the tactile perception of the fingers [24,25] during and after exposure, especially during the night-time [26]. Carpal tunnel syndrome [27], tendonitis, and bicipital epicondylitis [28] are observed, and several associations between physical workload factors and some common upper limb disorders are noted [29].

In general, numerous research has been done with regard to the measurement of the vibration and the noise generated by chainsaw during felling and cross-cutting operations, according to the chainsaw technologies [15,30–32] as well in terms of wood characteristics [33]. Anyway, no studies so far have examined the potential levels of acoustic and vibrations pressures on agroforestry farms in which a desultory use of chainsaws is more evident. As a consequence, the present work collected a set of nine chainsaws currently used by a sample of self-employed forest owners.

The aim of this paper is to determine if there are significant differences in terms of operator exposure to noise and hand-arm vibrations due to use of chainsaws. In order to obtain a representative analysis of the present condition of exposure to the risk of noise and vibrations, the work was based on the collection of a random sample of chainsaws in agroforestry farms in the same condition of use declared by the chainsaw operators.

2. Materials and Methods

The study was conducted in the Sila area in the Calabria region (Southern Italy). This area is characterized by a large number of small-size agroforestry farms. To obtain a representative analysis, random old chainsaws were tested. The selection of the chainsaws was based on the identification of farms identified on the base of small-size dimension, forest management by the self-employed, and occasional use of the chainsaws.

Nine farms were selected, and each owner was informed with the aim of the study, and for this reason, each farm lends the chainsaw for the test. Therefore, nine different chainsaw models (Figure 1) were selected, and their characteristics are reported in Table 1. To reduce the uncertain variability, the study was developed under controlled conditions i.e., during the tests, the chainsaws were operated by the same operator, aged 48, with 20 years of work experience, and the field test was free from external artificial noises. The daily exposure values were normalized to three different scenarios: four, six, and eight hours, on the basis of information given from the owners.

Table 1. Chainsaw characteristics and the values declared by constructor.

Code	Power (kW)	Weight kg	Bar Size cm	Noise Sound Power—Pressure dB(A)	Vibration Front—Rear $m\ s^{-2}$	Years in Use	Annual Days of Use
A	4.4	6.7	50	105–117	3.8–4.0	5	35
B	2.6	4.7	40	102–110	3.4–4.3	8	45
C	3.9	6.2	45	103–115	4.6–5.2	12	40
D	3.5	5.6	46	101–112	4.0–5.9	15	45
E	3.2	6.2	50	102–112	4.4–6.1	20	50
F	2.3	6.1	40	102–112	6.4–7.2	25	40
G	3.4	6	40	103–112	3.8–5.1	14	50
H	3.6	6.4	45	108–119	4.0–5.1	8	40
I	2.1	4.3	40	104–112	5.2–5.5	11	45

Two different wood types, softwood (SW) and hardwood (HW), which are represented in this study by Corsican pine (*Pinus laricio* Poiret) and European beech (*Fagus sylvatica* L.), were considered to evaluate the influence of wood density on the vibrations and noises during the cross-cutting operations.

The cross-cutting tests were conducted on wood logs with an originally length of 2 m and a diameter ranging from 23 to 25 cm at the middle of their length. They were placed on a sawbuck 45 cm above ground, so that the operator was able to cut slices of approximately 5 cm width. Wood density was determined in laboratory (in according with ISO 13061-1) [34] using wood samples from each disc generated during the cross-cutting test. Oven-dry density results in 520 kg/m^3 and 715 kg/m^3, respectively, for Corsican pine and European beech.

Each chainsaw was tested using a saw directly sharpened by the owners, in order to not alter the common condition of use by them and to adopt the same cutting tooth profile. In fact, the purpose of this study has been to determine noise and vibration exposure in the typical using of a chainsaw in a small-scale agroforestry farm.

The situation without wood cross-cutting was therefore also considered. In this situation, the use of the chainsaws at full RPM (Rotation Per Minutes) rate (chainsaw engine running at the maximum), and at minimum RPM rate (chainsaw engine running without acceleration) were considered.

The cross-cutting was thus repeated 3 times for front and rear handles (A and B in Figure 2 and H in Formula 1) for each chainsaw (Figure 3). During the sampling of vibration applying minimum and maximum engine power, the test lasted 60 s for each mode. A total of 108 different combinations were registered and 324 measures were determined following this scheme:

$$N \times W \times H \times EP \times T \tag{1}$$

where:

N = 9 different chainsaws; W = 2 different wood species; H = 2 different handles; EP = 3 different RPM rates; T = 3 repetitions for each combination.

Figure 1. The nine chainsaws analyzed in this work.

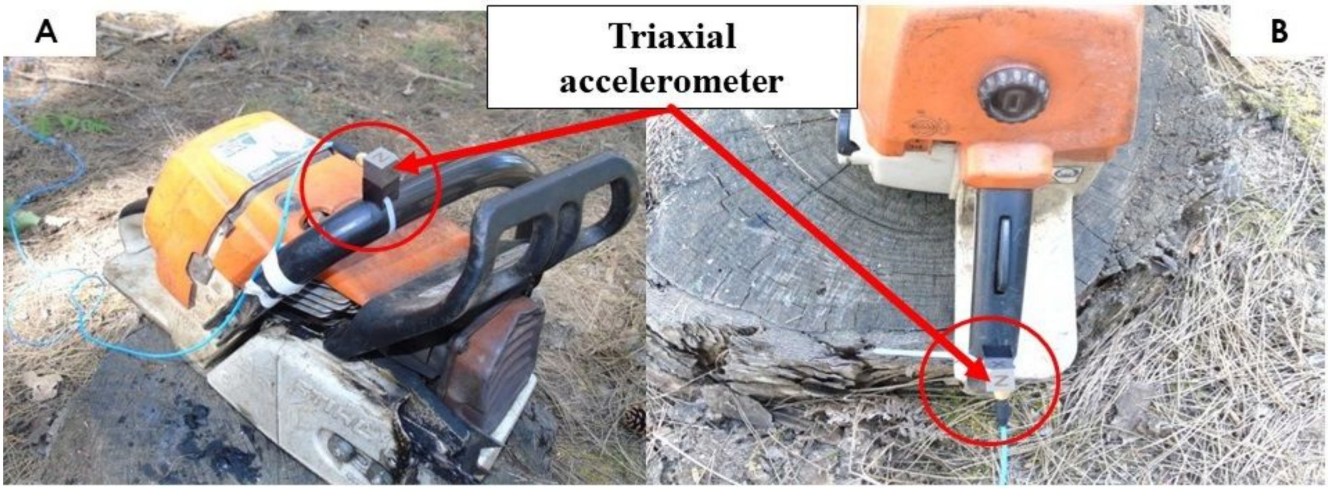

Figure 2. The triaxial accelerometers position on the chainsaw on the front (**A**) and rear (**B**) handles.

Figure 3. The noise and vibration measurements during cross-cutting operation.

Vibration and Noise Measurements

In accordance with ISO standard 5348 [35], vibrations were correctly measured using a cubic triaxial piezoelectric accelerometer ICP® (Integrate Current Preamplifier) by PCB Piezotronics (356A02 model, 10 mV/g sensitivity, 10.5 g mass) fixed on the chainsaw (Figure 2), and using an accelerometer mounting adapter following the orientation of the measurement axes as described in the ISO standards 5349:1-2 [36,37]. The accelerometer was mounted in a position that could not interfere with the operator during the cross-cutting. A cable of 5 m, which was connected the triaxial accelerometer, transferred the vibration measurements obtained in three perpendicular directions (ISO 5349-1) [37] on four channels vibration meter-analyzer Delta Ohm HD2030. Data were stored on a SD memory cards for post-processing analysis. The HD2030 analyzer complied with all measurements required by the European regulations regarding the protection of workers from exposure to mechanical vibrations. In particular, the frequency range of spectral analysis varies from 3.15 Hz up to 3.15 kHz, and for the analysis of octave band spectrum, the range applicable is 4 Hz to 2 kHz. The collected vibration data were analyzed with the Noise Studio software licensed with application module "Workers' Protection". Calibration was performed every time that changed the chainsaw tested using a calibrator portable Delta Ohm HD2060, which produces a frequency of 15.915 Hz and an acceleration signal of 1 m s^{-2}.

As reported in similar studies [16,23,33,38], the accelerations were simultaneously measured along the three perpendicular axes (a_x, a_y, a_z) following the recommendations of the EN ISO 20643/A1 standard [39], and the signals from the accelerometers were frequency weighted using the weighting curve Wh (ISO 5349-1 standard) [36]. Thus, the weighted acceleration levels in all three axes (a_{hwx}, a_{hwy} and a_{hwz}) were obtained, and the vibration total value (a_{hv}) was determined according to the following relation:

$$a_{hv} = \sqrt{a^2{}_{hwx} + a^2{}_{hwy} + a^2{}_{hwz}} \quad (2)$$

Progressively, the daily vibration exposure was derived from the magnitude of the vibration (vibration total value) and the daily exposure duration. Considering the use of these sampled chainsaws is occasional and non-continuous, three different reference periods were studied: four, six, and eight hours. The daily vibration exposure has been expressed in terms of the h energy-equivalent frequency-weighted vibration total value:

$$A(h) = ahv\ \sqrt{\frac{T}{T_0}} \quad (3)$$

where T is the total daily duration of exposure to the vibration a_{hv} and T_0 is the reference duration of h hours. The considered h in this study had values of 4, 6, or 8 h.

Simultaneously, the sound pressure level was monitored according to the international standards (ISO 9612) [40] and European Directive [13]. The tests have been carried out with the use of a precision integrator phonometer, Delta Ohm HD 9020 class 1, connected with a 10 mt extension cable to a microphone MK221, which was fixed to the helmet and placed 10 cm from the worker's right ear. The sound level meter was able to perform the measurements required to evaluate workers' noise exposure [40,41]. This instrument is set every year at the laboratory S.I.T. (Italian Calibration Service—Accredia), and after each chainsaw series of measurements, the setting was controlled by calibrator Delta Ohm HD 9101. The acoustic levels and noise generated during the tests have been stored using a SD memory card (2 GB) allocated in the sound meter and transferred through a serial cable to a laptop to be processed successively, using the same software used for vibration data. Following the guidelines of ISO 9612 [40], the equivalent continuous sound pressure level (L_{eq}) with full sound frequency spectrum in 1/3 octave bands and the maximum value of the instantaneous sound pressure (L_{peak}) were calculated; the acoustic levels obtained were expressed in decibels (dB), adjusted to curve A (LA_{eq}) and curve C (LC_{peak}). Similarly to vibrations exposure, the sound pressure level was been expressed in terms of the h energy-equivalent frequency-weighted noise total value (L_{EX},h) with equation

$$L_{EX,h} = LA_{eq,Te} + 10 \log (T_e/T_0)(dB(A)) \quad (4)$$

$$LA_{eq,Te} = 10\ \log \{\frac{1}{T_e}\int_0^{T_e}\left[\frac{P_A(t)}{P_0}\right]^2 dt\} \quad (5)$$

where:

T_e = period of a worker's personal exposure to noise;
T_0 = 4, 6, or 8 h;
P_A = instantaneous acoustic pressure (weighting scale A), in Pa;
P_0 = 20 μPa.

3. Statistical Analysis

To identify and explain the sources of variation in (*i*) vibration total value (a_{hv}) (Formula 2) and in the equivalent (*ii*), continuous sound pressure level (L_{eq}) was adjusted to curve A (LA_{eq}) based on chainsaw model, chainsaw engine RPM rates, wood species, and wood moisture content. A multifactor analysis of variance (multifactor-ANOVA) would be applied to better understand the effect of the covariates, factors, and the relationships between them.

ANOVA table decomposes the variability of the vibration total value (a_{hv}) or the equivalent continuous sound pressure level (L_{eq}) adjusted to curve A (LA_{eq}) into contributions due to various factors. Since Type III sums of squares (the default) have been chosen, the contribution of each factor was measured having removed the effects of all other factors. The *p*-values test the statistical significance of each of the factors by considering *p*-values less than 0.05 at the 95.0% confidence level.

The method used thus to discriminate among the means will be the Fisher's least significant difference (LSD). With this method, there is a 5.0% risk of calling each pair of means significantly different when the actual difference equals 0.

The statistical analyses were supported by STATGRAPHICS Centurion 19® and R.

4. Results

Table 2 shows the vibration total value (a_{hv}) on front and rear position according to two cases (*i*) the minimum and maximum RPM rates and (*ii*) the different type of wood (Corsican pine—softwood and European beech—hardwood) during the cross-cutting operation.

Table 2. Means of the vibration total value (a_{hv}) and mean of peak level (a_{pl}).

				a_{hv}, m s^{-2}					
	Minimum RPM		**Maximum RPM**			**Cross-Cutting**			
Code	**Front**	**Rear**	**Front**	**Rear**	**Code**	**Front SW**	**Front HW**	**Rear SW**	**Rear HW**
A ^{cde}	4.08	4.31	4.60	4.90	A ^{b}	5.04	6.15	6.74	7.61
B ^{bcd}	3.57	4.56	4.78	5.29	B ^{b}	4.46	4.69	6.54	6.79
C ^{a}	2.75	3.24	4.62	5.13	C ^{a}	3.41	3.51	5.37	4.93
D ^{e}	3.31	4.03	5.06	5.54	D ^{d}	5.61	5.79	10.69	11.64
E ^{abc}	3.18	4.24	3.77	4.35	E ^{ab}	3.73	4.02	7.89	7.12
F ^{abc}	3.17	4.50	4.71	4.88	F ^{c}	7.89	7.95	8.09	8.16
G ^{bcde}	2.48	5.78	4.13	5.64	G ^{ab}	4.37	6.41	7.09	7.27
H ^{ab}	3.82	3.56	4.03	4.80	H ^{b}	4.92	5.55	7.23	7.60
I ^{ab}	3.28	4.50	4.44	4.95	I ^{c}	8.02	8.72	8.34	8.88
				a_{pl}, m s^{-2}					
Code	**Minimum RPM**		**Maximum RPM**			**Cross-Cutting**			
	Front	**Rear**	**Front**	**Rear**		**Front SW**	**Front HW**	**Rear SW**	**Rear HW**
A ^{a}	3.23	3.77	4.07	3.50	A ^{abc}	2.73	2.78	5.04	4.92
B ^{a}	2.36	3.62	3.87	4.65	B ^{ab}	2.79	3.09	4.20	4.65
C ^{d}	2.84	2.79	4.36	2.47	C ^{a}	2.28	2.65	3.65	3.02
D ^{b}	2.66	2.58	4.99	6.64	D ^{e}	3.73	3.88	10.21	11.93
E ^{a}	2.97	2.76	2.58	5.04	E ^{ab}	2.73	2.50	4.98	4.42
F ^{c}	2.17	3.49	3.76	4.12	F ^{c}	5.40	5.92	4.43	5.12
G ^{a}	1.76	3.72	3.33	6.79	G ^{ab}	2.52	2.84	5.37	5.12
H ^{a}	3.51	2.33	3.60	3.08	H ^{bc}	3.57	3.52	5.76	6.11
I ^{b}	3.23	2.92	3.08	3.98	I ^{d}	6.29	6.57	6.15	5.25

SW = Corsican pine; HW = European beech. Superscript letters in CODE indicate similar values (LSD's test).

In the case (*i*), the multifactor analysis of variance highlights that the a_{hv} (m s^{-2}) is significantly affected by the RPM rates (*p*-value < 0.000), the chainsaw model (*p*-value 0.001), and the accelerometer position (rear vs. front handle) (*p*-value < 0.000). The higher effect is due to the RPM rate (57.76% of the variability) followed by the accelerometer position (29.08%) and the chainsaw model (3.41%).

The Fisher's least significant difference (LSD) procedure was applied to determine which a_{hv} means are significantly different from each other. The LSD test indicates that 11 pairs show statistically significant differences at the 95.0% confidence level and five homogenous groups within which there are no statistically significant differences of a_{hv} (Groups: C, H, I, E, and F; H, I, E, F and B; E, F, B, and G; B, G, and A; B, G, A and D). According to the LSD test, the pair difference is significative for the models A vs. C, A vs. H, A vs. I, B vs. C, C vs. D, C vs. G, D vs. E, D vs. F, D vs. H, D vs. I and G vs. H. A particular case is I which resulted in a high level of vibration in rear position in both RPM test condition. This situation was affected by the critical condition of vibration isolators.

The minimum RPM rates result in a similar level of a_{hv} in front handle position for almost all the chainsaw models (less than 4 m s^{-2}). In the case of the rear handle, almost all the chainsaw models exceeded the value 4 m s^{-2}, and only C and H resulted lower.

In the case (*ii*), the cross-cutting test aimed to evaluate a_{hv} on front and rear handles positions, due to the different type of wood and the different chainsaw models.

The multifactor analysis of variance indicates a p-value < 0.000 for the front and rear handle position and for the chainsaw model. These factors have a statistically significant effect on a_{hv} at the 95.0% confidence level. In the case of the types of wood factor, the p-value resulted higher than 0.05 and thus is not significant.

The Fisher's least significant difference (LSD) procedure was applied to determine which a_{hv} means are significantly different from which others. The LSD test indicates that 23 pairs show statistically significant differences at the 95.0% confidence level and four homogenous groups within which there are no statistically significant differences of a_h are identified (Groups: C, G, and E; G, E, B, H and A; F and I; D)

The chainsaws F and I have generated similar vibration values for both handles without differences between softwood and hardwood (Figure 4), as shown by the LSD test. The other chainsaws reported a significant difference between the rear and front handle position: on average +44% during cross-cutting of softwood and +38% for hardwood. Anyway, the differences considering the type of wood used result in being slightly not significant (p-value 0.055), probably due to the high effect due to the chainsaw type. Consequently, the vibration values during the cross-cutting of Corsican pine and European beech were not statistically different, disproving the experimental hypothesis, despite comparing a softwood with a hardwood species.

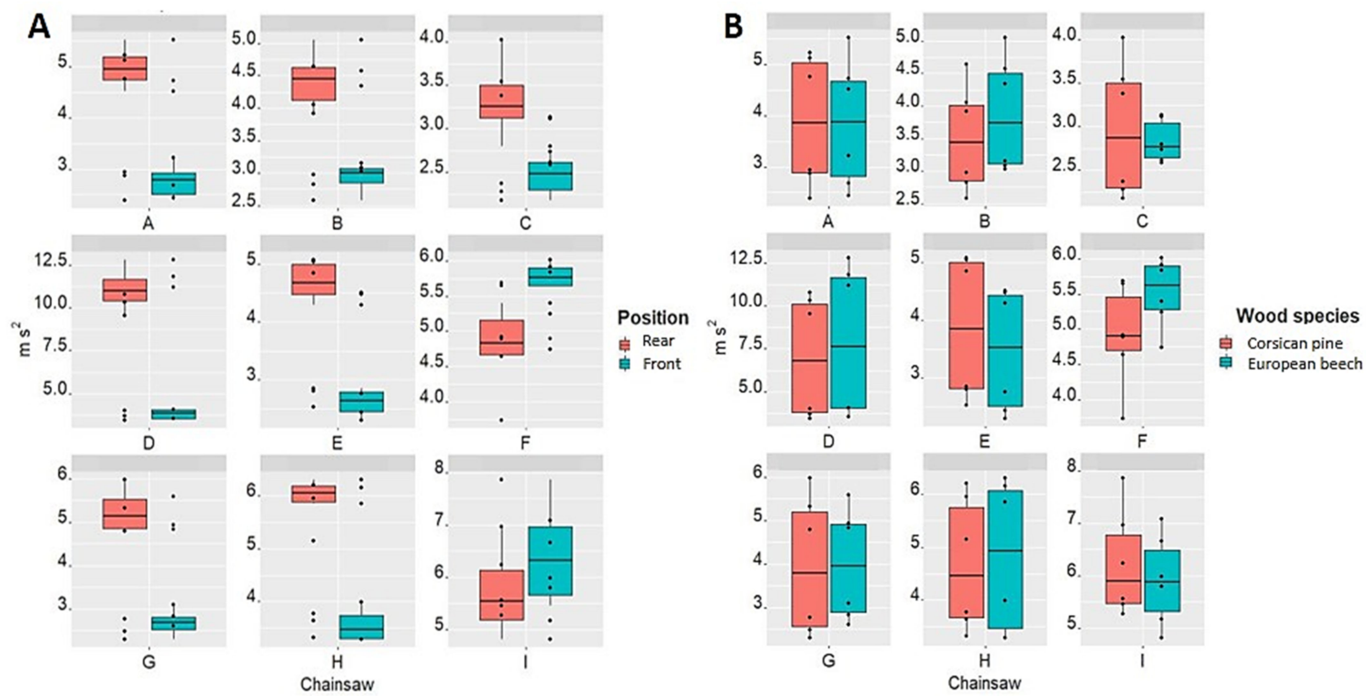

Figure 4. The graphical representation of the vibration peak level a_{pl} during minimum and maximum RPM (case *i*) (**A**) and during cross-cutting operation (**B**) (case *ii*) where A–I represent the chainsaw models.

The vibration amplitude, which is the characteristic that describes the severity of the vibration, can also be represented by the peak level (a_{pl}). The a_{pl} can be used to indicate the acceleration shocks.

In the case (*i*) for the evaluation of the a_{pl} on front and rear position according to the minimum and maximum RPM rates, the multifactor analysis of variance highlights that the a_{pl} (m s^{-2}) is significantly affected by the RPM rates (*p*-value < 0.000), the chainsaw model (*p*-value = 0.038), and the accelerometer position (rear vs. front handle) (*p*-value = 0.011). The higher effect is due to the RPM rate (67.13% of the variability) followed by the chainsaw model (18.31%) and the accelerometer position (12.77%).

Additionally, for the a_{pl}, the evaluation of the effect of the type of wood (Corsican pine—softwood and European beech—hardwood) during the cross-cutting operation has been evaluated.

The effect is clear for chainsaw model (*p*-value < 0.000) and for the accelerometer position (front and rear) (*p*-value < 0.000), while wood type is significant but slighter than the previous effects (*p*-value = 0.017).

The Fisher's least significant difference (LSD) procedure was applied to determine which a_{pl} means are significantly different from which others. The LSD test indicates that 19 pairs show statistically significant differences at the 95.0% confidence level and five homogenous groups within which there are no statistically significant differences of a_{pl} (Groups: C, E, B, G, and A; E, B, G, A and H; A, H and F; F and I; D).

The Table 3 reports L_{Aeq} and L_{Cpeak} according to two cases: (*i*) the minimum and maximum RPM rates, and (*ii*) the different type of wood (Corsican pine—softwood and European beech—hardwood) during the cross-cutting operation.

Table 3. Noise measurements in terms of L_{Aeq} and LC_{peak} (dB(A)).

	L_{Aeq}			L_{Cpeak}	
Code	**Min RPM**	**Max RPM**	**Code**	**Min RPM**	**Max RPM**
A ^{cd}	82.04	99.95	A ^{b}	101.66	116.07
B ^{ab}	75.74	95.36	B ^{a}	91.24	110.63
C ^{ab}	72.68	100.69	C ^{b}	98.48	114.94
D ^{d}	85.83	100.85	D ^{b}	101.74	113.81
E ^{bcd}	78.32	102.29	E ^{b}	100.81	116.19
F ^{d}	85.39	105.03	F ^{c}	108.15	119.32
G ^{cd}	76.66	99.47	G ^{b}	96.72	112.46
H ^{a}	73.71	98.43	H ^{a}	97.51	113.69
I ^{a}	80.62	89.91	I ^{a}	100.93	104.63
Cross-Cutting Operation					
Code	L_{Aeq} **SW**	**HW**	**Code**	L_{Cpeak} **SW**	**HW**
A ^{b}	88.59	90.82	A ^{a}	105.64	106.41
B ^{a}	85.92	86.44	B ^{a}	100.31	100.84
C	89.02	89.81	C ^{a}	102.87	103.12
D ^{ab}	88.11	88.19	D ^{a}	103.11	103.78
E ^{bc}	90.01	90.29	E ^{b}	103.94	105.24
F ^{d}	92.92	94.55	F ^{d}	111.87	112.17
G ^{b}	88.31	91.52	G ^{a}	102.88	103.19
H ^{bc}	89.19	91.71	H ^{b}	105.82	107.11
I ^{bc}	90.31	91.44	I ^{b}	108.51	109.42

SW = Corsican pine; HW = European beech. Superscript letters in CODE indicate similar values (LSD's test).

In the case (*i*), the multifactor analysis of variance highlights that the L_{Aeq} is significantly affected by the RPM rates (*p*-value < 0.000) and the chainsaw model (*p*-value 0.002). The higher effect is due to the RPM rate (84.49% of the variability) followed by the chainsaw model (16.45%).

The Fisher's least significant difference (LSD) procedure was applied to determine which L_{Aeq} means are significantly different from which others. The LSD test indicates that 16 pairs show statistically significant differences at the 95.0% confidence level and four homogenous groups within which there are no statistically significant differences of L_{Aeq} (Groups: H, I, C, and B; B, C and E; C, E, A and G; E, A, G, D and F).

Again, in the case (*i*), the multifactor analysis of variance highlights that the L_{Cpeak} is significantly affected by the RPM rates (*p*-value < 0.000) and the chainsaw model (*p*-value < 0.000). The higher effect is due to the RPM rate (77.85% of the variability) followed by the chainsaw model (21.07%).

The Fisher's least significant difference (LSD) procedure was applied to determine which L_{Cpeak} means are significantly different from which others. The LSD test indicates that 23 pairs show statistically significant differences at the 95.0% confidence level and three homogenous groups within which there are no statistically significant differences (Groups: B, I and H; C, D, G, E and A; F).

According to the evaluation of the L_{Aeq} and L_{Cpeak} in relation to the different types of wood (Corsican pine—softwood and European beech—hardwood) during the cross-cutting operation (case *ii*), the same statistical approach of the case *i*) is applied.

The multifactor analysis of variance highlights that the L_{CAeq} is significantly affected by the chainsaw model (*p*-value < 0.000) and not significantly affected by the wood tree species (*p*-value 0.967). The effect due to the chainsaw model is estimated in 81.40% of the total variability.

The Fisher's least significant difference (LSD) procedure was applied to determine which L_{CAeq} means are significantly different from which others. The LSD test indicates that 15 pairs show statistically significant differences at the 95.0% confidence level and four homogenous groups within which there are no statistically significant differences (Groups: B and D; D, A, G, I, E and H; I, E, and H; F).

By considering L_{Cpeak}, the multifactor analysis of variance highlights that the L_{Cpeak} is significantly affected by the chainsaw model (*p*-value < 0.000) and not significantly affected by the wood tree species (*p*-value 0.449). The effect due to the chainsaw model is estimated in 72.84% of the total variability.

The Fisher's least significant difference (LSD) procedure was applied to determine which L_{Cpeak} means are significantly different from each other. The LSD test indicates that 24 pairs show statistically significant differences at the 95.0% confidence level, and four homogenous groups within which there are no statistically significant differences (Groups: B; C, G, D and A; E, H and I; F).

The noise test indicates significant differences between the chainsaw models by considering minimum and maximum RPM. In the case of minimum RPM, the displacement of each chainsaw examined has not completely influenced the acoustic levels products.

In fact, the chainsaws F (2.3 kW) and I (2.1 kW) have major noise values respective to models with a higher engine displacement; this result is not supported during the maximum speed where the more powerful chainsaws generated higher noise. As can be seen in Table 3 and Figure 5, during the cross-cutting operations, each chainsaw produced high acoustic levels. LA_{eq} values are in all the cases above 87 dB(A) with some of them even reaching 100 dB(A). Indeed, peak values turn out to be high, even though they never exceed the peak as required by the law in force.

Compared to the European legislation and to the noise exposure assessment standards [42], the results of this study indicate that in most of the observed tasks, the exposure to noise exceeded the 80 dB(A) lower exposure action level. The noise levels for the study sample were normally distributed, with the majority of the "noisy" equipment operated in the region of 90 dB(A) to less than 85 dB(A) [43]. This situation should be considered to permit a correct application of PPE during this use. There are four general types of passive hearing protection devices: earplugs, semi-insert or ear canal caps, earmuffs, and helmets. In particular, headphones could be used, as some studies have already tested their ability to reduce the noise levels that reach the operator [31–42]. Considering the occasional, not continuous use of these sampled chainsaws, Table 4 evaluated the noise and vibration emissions considering different daily exposure values to three different reference periods: 4, 6, and 8 h.

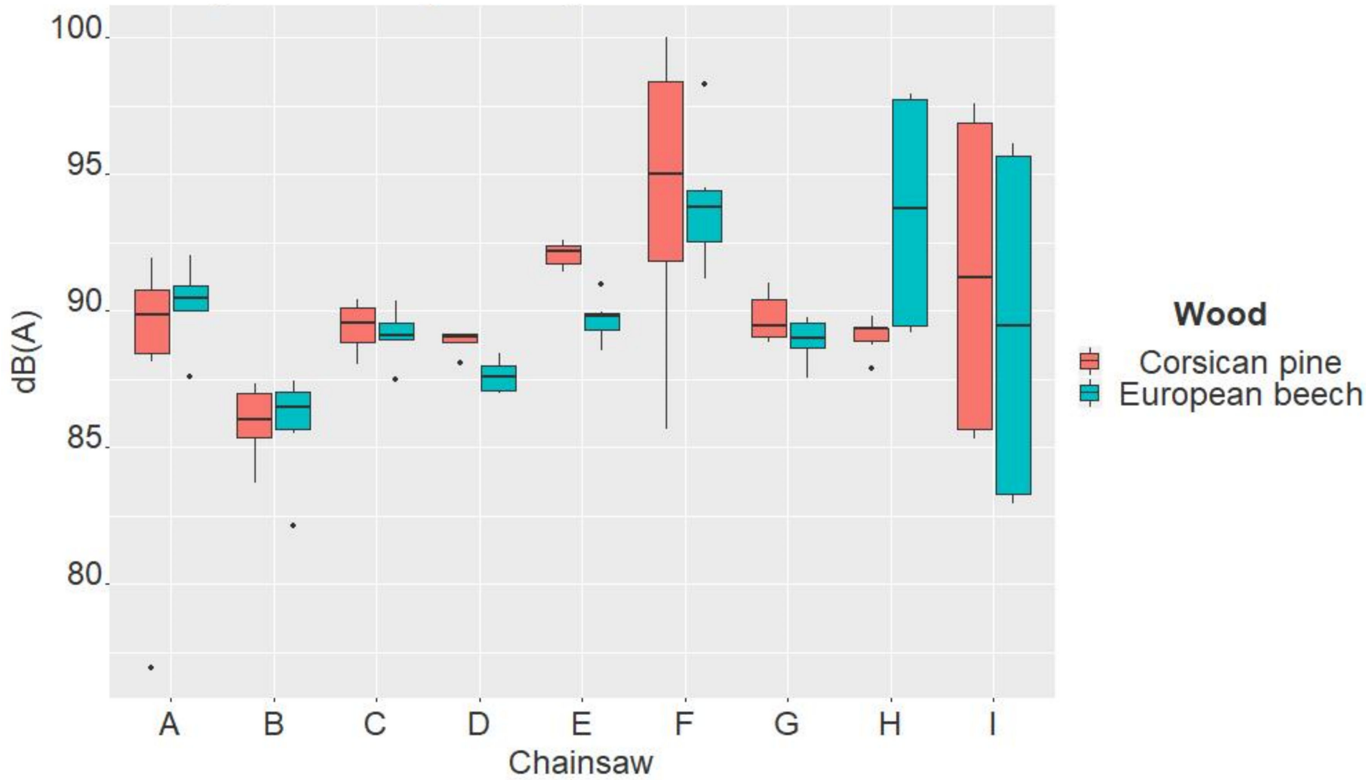

Figure 5. Average 8 h A-weighted equivalent continuous noise level during cross-cutting phase.

Table 4. The noise and vibrations emissions of tested chainsaws considering different daily exposure values (4, 6, and 8 h scenarios).

Chainsaw Code	Noise dB(A) L_{EX}						Vibration m s^{-2}					
	4 h		6 h		8 h		4 h		6 h		8 h	
	SW	HW	SW	HW	SW	HW	SW	HW	SW	HW	SW	HW
A	85.6	87.8	87.3	89.6	88.6	90.8	4.7	5.4	5.8	6.6	6.7	7.6
B	82.9	83.4	84.7	84.9	85.9	86.4	4.6	4.8	5.7	5.9	6.5	6.8
C	86	86.8	87.8	88.6	89	89.8	3.8	3.5	4.6	4.3	5.3	4.9
D	85.1	85.2	86.9	87	88.1	88.2	7.5	8.2	9.3	10.1	10.7	11.6
E	87	87.3	88.8	89	90	90.3	5.0	5.6	6.2	6.9	7.1	7.8
F	89.9	91.5	91.7	93.3	92.9	94.6	5.7	5.8	7.0	7.1	8.1	8.2
G	85.3	88.5	87.1	90.3	88.3	91.5	5.0	5.2	6.2	6.3	7.1	7.3
H	86.2	88.7	87.9	90.5	89.2	91.7	5.1	5.4	6.3	6.6	7.2	7.6
I	87.3	88.4	89.1	90.2	90.3	91.4	5.9	6.3	7.2	7.7	8.3	8.9

SW = Corsican pine; HW = European beech.

Table 4 grouped the noise and vibrations emissions of tested chainsaws starting from the high values monitored during the cross-cutting operation for each different log. Compared to the European legislation and to the noise exposure assessment standards [13], the results indicate that each chainsaw exceeded the 80 dB(A) minimum action level, indiscriminately between wood type and hourly exposure. In the exposure interval of 4 and 6 h, only the chainsaw B did not exceed the daily threshold of 85 dB(A) in both wood types. However, the noise exposure based on 4 h showed values nearest to 87 dB(A) respective to 6 and 8 h, where the values went beyond the maximum allowable daily exposure threshold.

The differences in daily noise (L_{EX}) between chainsaws due to engine power or years of use have not highlighted important distinctions. This is a symptom of how noise remains a risk factor for human health strictly connected in the use of the chainsaw, whatever the model, the years of use, and the engine power.

Similarly to noise values, the daily vibration exposure value A (Table 4), normalized to three-different-hour reference periods, exceeded in all sampled chainsaws with the daily exposure action value of 2.5 m s^{-2}, limiting threshold beyond which it is mandatory to reduce exposure to this physical agent. Higher values were obtained in three different models of chainsaws (D, F, and I) in each different daily exposure. It could be assumed that the exposure values have been influenced by the years of use of the chainsaws but, in reality, a cause of a technical nature of the chainsaw itself seems more plausible. In fact, other chainsaws, with the same period of years of use, have showed lower vibration values. For example, chainsaw C, despite having about 12 years of use and a high engine power, generated lower vibration values than all the models tested. Therefore, the results showed that the differences in power and years of use between the different chainsaws confirm that the levels of exposure to these two physical risk agents (noise and vibrations) are highly variable and depend mainly on the type of chainsaw construction.

5. Discussion

Noise and vibration are closely linked [44]. The study evaluated together these two physical agents to determine the potential levels of acoustic and vibrations pressures on operator working occasionally in felling and bucking operations in agroforestry.

Noise and vibrations levels generated by a chainsaw are significant issues on agroforestry farms because they are not always considered a hazardous problem due to the short period (days/year) dedicated to wood harvesting.

As a consequence, the use of appropriate control measures and protection strategies, as well the evaluation of the vibration and noise exposition levels, are precautions to reducing the workload, noise, and musculoskeletal disorder risks.

In the case of professional use of the chainsaw, this is common daily maintenance, and the chainsaw periodically replaced to ensure the efficiency of sawing and reduce vibration and noise exposition levels. In the case of small-scale agroforestry context, chainsaws are hardly replaced, therefore the exposition to these physical agents increases.

Therefore, despite the technical progress developed by manufacturers to contain exposure to these risk agents, in small agroforestry the exposure limits are constantly exceeded. As reported by Landekić et al. [23], every chainsaw in professional forestry must undergo a verification process every three years in Croatia, and maintenance and replacement of parts must be in accordance with the manufacturers' recommendations. In addition to the replacement or valid maintenance of chainsaw, Calcante et al. [45], confirmed that reducing exposure to noise and vibration levels can be improved not only with the technological progress of the engine design, but above all by adopting advanced fuels that lead to a more efficient combustion process and consequently to reduce the vibration amplitudes.

The results obtained in the specific condition of the agroforestry farms in southern Italy partially reflect what was identified by previous studies [30,33], which considered chainsaws of the same age and in new conditions. In fact, in our study, it is clear that the vibration levels depend on the chainsaw model and occur according to the accelerometer position (front and rear handles), while the results of vibration levels on different wood types are significant, but slighter than the results when using different chainsaw models. In the case of Kováč et al. [30] (Norway spruce wood versus Scotch pine wood), and Rottensteiner et al. [33] (Norway spruce wood versus European beech wood and Black poplar wood), the impact of wood density is determined in terms of vibrations due to wood tree species and the consideration of the chainsaw as new. However, differences in years in the use of chainsaws seem to have not had an influence in terms of vibration exposure, as comparable values were measured despite the difference in age of use, as has been confirmed by Landekić et al. [23]. The study evaluated vibration levels separating 30 chainsaws into three groups of ages with an interval of years from three to ten years. In their study, the authors indicated that the daily vibration exposure was not affected by the years of use comparing three different types of professional chainsaws. This consideration supported the result of our study that added more information and data in the field of the safety and health of operators. In fact, as foreseeable, the daily vibration exposures A(6) and A(8) abundantly exceeded the limit value of 5 m s^{-2}, the sign indicated by several authors [15,23] to also be the low or total absence of maintenance. Instead, the scenario imagined with daily exposure of only 4 h, reduces the potential impact of vibrations for many of the chainsaws tested; perhaps it would be useful to indicate the maximum time of use per day for these types of chainsaws with a limit of 4 h.

As reported by EU Directive 2002/44/EC [19], vibration exposure is an important indicator in defining occupational safety measures, and each action must be developed to reduce this vibration hazard to a minimum. In terms of noise generated, the high values generated by each chainsaw exceeded the exposure limit of 85 dB(A), however this value was expected, as it was widely declared by the constructor (Table 1).

However, it is important to remember that after overtaking this value, it is necessary to take measures to eliminate negative values of noise to protect the health of workers. Almost all chainsaws overtake the daily exposure level A(4), and the noise value is in the range of 85–90 dB(A) for softwood and 85–91.5 dB(A) for hardwood. In this case, evaluating the aged chainsaws used and the non-continuous use, it is possible to control the noise with the reduction at the receiving point by wearing personal protective equipment (PPE) to control of the sound field. In fact, earmuffs or similar hearing protectors reduce the perceived noise level, thereby eliminating the danger of deafness. Another possible solution can be the reduction of time use in chainsaw work, as already suggested, for the reduction of vibration exposures.

Several and detailed previous studies [16,23,46] have aimed to compare the values of vibration and noise declared by constructed respect the occupational exposure limits without considering how these values can change over the years and even decades from their first use. This study added more information with respect the study conducted by Landekić et al. [23] that considered only three types of used professional chainsaws. Instead, at a non-professional level there is still a lack of information which translates into greater risk for operators, even if they work occasionally. Compared to other studies that have shown that engine power is the main cause of high noise levels [15,30,32,45], in this analysis, the data showed that years of use and association with low maintenance, can affect noise levels. If work of a chainsaw operator, even if occasional, is characterized by a large physical load and high risk of accidents, it also endangers his health in other ways, of which vibrations and noise are the most important [47]. In fact, Kovac et al. [30], suggested how inappropriate chainsaw operations, i.e., absence of maintenance and lack of safety equipment, may worsen the effects of noise and vibration.

Although the results of our study could be seen in the light of some important limitations, including for example the small representative sample of chainsaws used, the data obtained confirm previous but few studies that have examined used chainsaws many years after their first use [15,23]. Therefore, this information supports the need for continuous control of these tools, which are erroneously considered not harmful to human health only for their occasional use in small-scale agroforestry practices. In addition, these considerations are also supported by Calvo et al. [38], who provided reliable information on the service life and maintenance cost of chainsaws used in forest operations, estimating a service life of 8 years.

6. Conclusions

This study stands out for evaluating the variability in terms of exposure to vibrations and noise in the use of the chainsaw, as well as in its usual conditions of operators involved in the management of agroforestry systems. Some occupational health disorders, such as hearing losses, repetitive stress syndromes, and certain musculoskeletal trauma, are the subject of study and research among relevant international agencies, such as FAO and ILO, in countries with significant forestry sectors. In fact, wood harvesting exposes the operators to occupational disturbance levels and, in this perspective, this research is one of few studies focused on the monitoring the vibro-acoustic impacts on used chainsaws in small agroforestry companies. Among all nine samples of chainsaws examined, in fact, the chainsaw with fewer years of use, despite being the one with the highest engine power (kW), generated similar or sometimes lower noise levels compared to less powerful chainsaws. This consideration could be useful to focus once again on the importance of valid and correct maintenance, also and above all for small agroforestry companies that occasionally use these aged tools. In general, the study has confirmed the important role of correct maintenance of chainsaws. It has been verified that the use of aged and unprofessional chainsaws increases the risk factor due to the occurrence of noise and vibrations, but which are not strictly influenced by the type of wood sawn. The results of this work should be interpreted as being indicative as they account for a descriptive case study which can prove its utility and replicability in similar conditions in all agroforestry farms in which the use of chainsaw is low frequent. It is advisable to consider this aspect to start information programs suitable for semi-professional and occasional operators in the use of chainsaws in order to address the operators to better maintenance the chainsaw, reduce the risk of work-related diseases, and increase the level of safety. In further research, it would be interesting to repeat the experiment in other work phases (e.g., felling and delimbing) or testing the same chainsaws before and after valid and specialized maintenance. Despite different health impacts, noise and vibration hazards have similar sources, behave similarly and, from a prevention perspective, the controls have a similar approach. An improvement in the maintenance of used chainsaws may be the first step to reducing the exposures. This solution can be done only with periodic education and training on noise and vibration hazards in ensuring that a safety management program is an integral part of the work environment. In particular, for organizational measures, in addition to the use of PPE, such as gloves and handles which reduce the vibration transmitted to the hand-arm system, rest pauses should be scientifically designed to ensure cardiovascular recovery, and also to limit the exposure to noise during the operational time.

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References

1. Mueller-Darss, H. The significance of ergonomics to agroforestry, Part I. *Agrofor. Syst.* **1982**, *1*, 41–52. [CrossRef]
2. Mueller-Darss, H. The significance of ergonomics to agroforestry, Part II. *Agrofor. Syst.* **1983**, *1*, 205–224. [CrossRef]
3. Balasubramanian, V.; Egli, A. The role of agroforestry in the farming systems in Rwanda with special reference to the Bugesera-Gisaka-Migongo (BGM) region. *Agrofor. Syst.* **1986**, *4*, 272–289. [CrossRef]
4. Den Biggelaar, C. *Farmer Experimentation and Innovation: A Case Study of Knowledge Generation Processes in Agroforestry Systems in Rwanda*; FAO: Rome, Italy, 1996.
5. Den Biggelaar, C.; Gold, M.A. Development of utility and location indices for classifying agroforestry species: The case of Rwanda. *Agrofor. Syst.* **1996**, *34*, 229–246. [CrossRef]
6. Kleinn, C. On large-area inventory and assessment of trees outside forests. *Unasylva* **2000**, *200*, 3–10.

7. Ndayambaje, J.D.; Heijman, W.J.M.; Mohren, G.M.J. Household determinants of tree planting on farms in rural Rwanda. *Small-Scale For.* **2012**, *11*, 477–508. [CrossRef]
8. Neely, G.; Wilhelmson, E. Self-reported incidents, accidents, and use of protective gear among small-scale forestry workers in Sweden. *Saf. Sci.* **2006**, *44*, 723–732. [CrossRef]
9. FAO. Accident Reporting and Analysis in Forestry. 2018. Available online: www.fao.org/publications (accessed on 30 June 2022).
10. Monarca, D.; Biondi, P.; Cecchini, M.; Santi, M.; Guerrieri, M.; Colantoni, A.; Colopardi, F. Transmission of vibrations from portable agricultural machinery to the hand-arm system (HAV): Risk assessment and definition of exposure time for daily action and exposure limits. In Proceedings of the International Conference: Innovation Technology to Empower Safety, Health and Welfare in Agriculture and Agro-Food Systems, Ragusa, Italy, 15–17 September 2008.
11. Bolaji, B.O.; Olanipekun, M.U.; Adekunle, A.A.; Adeleke, A.E. An analysis of noise and its environmental burden on the example of Nigerian manufacturing companies. *J. Clean. Prod.* **2018**, *172*, 1800–1806. [CrossRef]
12. Hu, S.; Mu, Y.; Liu, G.; Zhang, L. Research on effecting mechanism of environmental parameters on human ear. *Build. Environ.* **2017**, *118*, 289–299. [CrossRef]
13. Directive 2003/10/EC of the European Parliament and of the Council of 6 February 2003 on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (noise). *Off. J. Eur. Union* **2003**, *L42*, 38–44.
14. Dobie, R.A. The burdens of age-related and occupational noise-induced hearing loss in the United States. *Ear Hear.* **2008**, *29*, 565–577. [CrossRef] [PubMed]
15. Neri, F.; Laschi, A.; Foderi, C.; Fabiano, F.; Bertuzzi, L.; Marchi, E. Determining noise and vibration exposure in conifer cross-cutting operations by using Li-Ion batteries and electric chainsaws. *Forests* **2018**, *9*, 501. [CrossRef]
16. Dixon, W. Effects of high intensity sound. In *Handbook of Acoustics*; Crocker, M.J., Ed.; Wiley & Sons Inc.: Hoboken, NJ, USA, 1998; ISBN 978-0-471-25293-1.
17. Fonseca, A.; Aghazadeh, F.; de Hoop, C.; Ikuma, L.; Al-Qaisi, S. Effect of noise emitted by forestry equipment on workers' hearing capacity. *Int. J. Ind. Ergon.* **2015**, *46*, 105–112. [CrossRef]
18. Neitzel, R.; Yost, M. Task-based assessment of occupational vibration and noise exposures in forestry workers. *AIHA J.* **2002**, *63*, 617–627. [CrossRef] [PubMed]
19. Directive 2002/44/EC of the European parliament and of the Council of 25 June 2002 on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (vibration) (sixteenth individual Directive within the meaning of Article 16(1) of Directive 89/391/EEC). *Off. J. Eur. Union* **2002**, *L177*, 13–20.
20. Goglia, V.; Suchomel, J.; Žgela, J.; Đukić, I. Forestry workers' exposure to vibration in the context of Directive 2002/44/EC. *Šumarski List* **2012**, *136*, 283–288.
21. Goglia, V.; Suchomel, J.; Žgela, J.; Đukić, I. The effectiveness of forest pre-commercial thinning in the context of Directive /44/EC. *Šumarki List* **2012**, *136*, 471–478.
22. Yovi, E.Y.; Yamada, Y. Addressing occupational ergonomics issues in Indonesian forestry: Laborers, operators, or equivalent workers. *Croat. J. For. Eng.* **2019**, *40*, 351–363. [CrossRef]
23. Landekić, M.; Bačić, M.; Pandur, Z.; Šušnjar, M. Vibration levels of used chainsaws. *Forests* **2020**, *11*, 249. [CrossRef]
24. Brammer, A.J.; Pyykkö, I. Vibration-induced neuropathy: Detection by nerve conduction measurements. *Scand. J. Work Environ. Health* **1987**, *13*, 317–322. [CrossRef]
25. Seppäläinen, A.M. Peripheral neuropathy in forest workers. A field study. *Work Environ. Health* **1972**, *9*, 106–111.
26. Färkkilä, M.; Aatola, S.; Starck, J.; Pyykko, I.; Korhonen, O. Vibration induced neuropathy among forest workers. *Acta Neurol. Scand.* **1985**, *71*, 221–225. [CrossRef] [PubMed]
27. Koskimies, K.; Pyykko, I.; Starck, J.; Inaba, R. Vibration syndrome among Finnish forest workers between 1972 and 1990. *Int. Arch. Occup. Environ. Health* **1992**, *64*, 251–256. [CrossRef] [PubMed]
28. Bovenzi, M.; Giannini, F.; Rossi, S. Vibration-induced multifocal neuropathy in forestry workers: Electrophysiological findings in relation to vibration exposure and finger circulation. *Int. Arch. Occup. Environ. Health* **2000**, *73*, 519–527. [CrossRef] [PubMed]
29. Viikari-Juntura, E. Risk factors for upper limb disorders. *Implications for prevention and treatment. Clin. Orthop. Relat. Res.* **1998**, *351*, 39–43. [CrossRef]
30. Kováč, J.; Krilek, J.; Dado, M.; Beňo, P. Investigating the influence of design factors on noise and vibrations in the case of chainsaws for forestry work. *FME Trans.* **2018**, *46*, 513–519. [CrossRef]
31. McLain, S.C.; Autenrieth, D.A.; Yang, X.; Brazile, W.J. Noise exposures and hearing protector use at small logging operations. *Small-Scale For.* **2020**, *20*, 1–9. [CrossRef]
32. Poje, A.; Potočnik, I.; Mihelič, M. Comparison of electric and petrol chainsaws in terms of efficiency and safety when used in young spruce stands in small-scale private forests. *Small-Scale For.* **2018**, *17*, 411–422. [CrossRef]
33. Rottensteiner, C.; Tsioras, P.; Stampfer, K. Wood density impact on hand-arm vibration. *Croat. J. For. Eng.* **2012**, *33*, 303–312.
34. *ISO 13061-1:2014*; Physical and Mechanical Properties of Wood—Test Methods for Small Clear Wood Specimens—Part 1: Determination of Moisture Content for Physical and Mechanical Tests. International Standards Organisation: Geneva, Switzerland, 2014.
35. *ISO 5348:1998*; Mechanical Vibration and Shock—Mechanical Mounting of Accelerometers. International Standards Organisation: Geneva, Switzerland, 1998.

36. *ISO 5349-1:2001*; Mechanical Vibration—Measurement and Evaluation of Human Exposure to Hand-Transmitted Vibration—Part 1: General Requirements. International Organization for Standardization: Geneva, Switzerland, 2001.
37. *ISO 5349-2:2001*; Mechanical Vibration—Measurement and Evaluation of Human Exposure to Hand-Transmitted Vibration—Part 2: Practical Guidance for Measurement at the Workplace. International Organization for Standardization: Geneva, Switzerland, 2001.
38. Calvo, A.; Deboli, R.; Preti, C.; de Maria, A. Daily exposure to hand arm vibration by different electric olive beaters. *J. Agric. Eng.* **2014**, *45*, 103–110. [CrossRef]
39. *EN ISO 20643/A1:2012*; Mechanical Vibration—Hand-Held and Hand-Guided Machinery—Principles for Evaluation of Vibration Emission—Amendment 1: Accelerometer Positions. European Committee for Standardisation: Brussels, Belgium, 2012.
40. *UNI ISO 9612:2011*; Acoustics—Determination of Occupational Noise Exposure—Engineering Method. UNI: Milano, Italy, 2011.
41. *UNI 9432: 2011*; Acoustics—Determination of the Level of Personal Exposure to Noise in Working Environment. UNI: Milano, Italy, 2011.
42. Cheţa, M.; Marcu, M.V.; Borz, S.A. Workload, exposure to noise, and risk of musculoskeletal disorders: A case study of motor-manual tree feeling and processing in poplar clear cuts. *Forests* **2018**, *9*, 300. [CrossRef]
43. Depczynski, J.; Fanklin, R.C.; Challinor, K. Farm noise emissions during common agricultural activities. *J. Agric. Saf. Health* **2005**, *11*, 325–334. [CrossRef]
44. International Labour Organization. *Physical Hazards: Noise & Vibration*; International Labour Organization: Geneva, Switzerland, 2012; 30p, ISBN 978-0-9808743-1-0.
45. Calcante, A.; Facchinetti, D.; Pessina, D. Analysis of hazardous emissions of hand-operated forestry machines fuelled with standard mix or alkylate gasoline. *Croat. J. For. Eng.* **2018**, *39*, 109–116.
46. Rukat, W.; Jakubek, B.; Barczewski, R.; Wróbel, M. The influence of the direction of wood cutting on the vibration and noise of chainsaws. *Teh. Vjesn.* **2020**, *27*, 1879–1886.
47. Stempski, W.; Jabłoński, K.; Wegner, J. Relations between top-plate filling angle values of cutting chains and chainsaw vibration levels. *Acta Sci. Pol.* **2010**, *9*, 31–39.