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Vito Ferro · Giuseppe Giordano · Santo Orlando · Mariangela Vallone · Giovanni Cascone · Simona M. C. Porto *Editors*

AIIA 2022: Biosystems Engineering Towards the Green Deal

Improving the Resilience of Agriculture, Forestry and Food Systems in the Post-Covid Era

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Contents

Experimental Analysis of Chainsaw Emissions in Chestnut Wood Operations

Francesco Toscano, Paola D'Antonio, Carmen D'Antonio, Nicolino De Iorio, Felice Modugno, and Costanza Fiorentino

Abstract In Italy, the orography of the territory, the medium-small size of the farms and the composition of the wooded capital (prevalence of hardwoods governed by coppice) make it easier to use chainsaws for in field operations of Felling (FE), Delimbing (DE) and Bucking (BU). With the spread of chainsaws, there is an increase in the incidence of injuries and illnesses caused by exposure to physical (noise, dust and vibrations) and chemical (volatile compounds of various kinds) agents. The legislation on occupational health and safety in Italy has followed various phases, first of all the approval of the U.T. 81/2008.

In the present work, the concentration of pollutants contained in the chainsaw exhaust gases (CO, VOC and C_6H_6) is evaluated with respect to the limits set by current legislation during interventions on a chestnut coppice. The correlation between the type of work performed (FE, DE, BU) and the ratio between the maximum and average values of CO and VOC was analysed. In particular, similar levels of maximum VOC emissions were recorded in the FE and BU phases, however in the same phases the average emission values were particularly different, suggesting a greater production of VOC in condition of the engine running but not operating at cut-off. The greatest emissions occurred in the FE phase (CO = 135 ppm, VOC = 17.28 ppm and C_6H_6 = 2.13 ppm).

Secondly, the noise emitted by the chainsaw during the exploitation of the chestnut coppice was analysed. It was found that the legal limits were exceeded during all chainsaw operations, with peaks of over 110 dB. The analysis revealed that the legal limits were respected only during the delimbing operation.

Keywords Injuries · Chainsaw · Forest utilizations · Occupational health · Noise

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1 Introduction

The increase in portable equipment for urban green care and maintenance and for hobbies has generated serious problems in terms of operator safety and ergonomics [3, 4, 6]. Often these are tools purchased online and without any training before use. Moreover, in the forestry sector, even after the advent of state-of-the-art machines and systems, the chainsaw is still undoubtedly the main machine with which to carry out felling operations, delimbing logs, and bucking timber into various assortments. The reason for this is the complex orography of the Italian territory. In fact, this is characterised by a significant steepness, which is even more accentuated in wooded areas, since lowland and hillside forests have long since given way to agricultural land. Secondly, Italian forestry companies are mostly medium or small, and therefore very often unable to bear the costs of purchasing, depreciating and managing state-of-the-art machinery. Another determining factor in determining inadequate machinery [10] fleets is the nature of the organisational structure and the composition of the wood capital of forestry companies. According to data from the RAF Italy 2017–2018, at the national level about 66% of forests are privately owned, while the remaining 34% are publicly owned. As far as private enterprises are concerned, there is also an extreme fragmentation of extensions, which, together with the prevalence of broadleaf forests, often coppice-governed, makes the application of Harvester and similar methods rather difficult. Moreover, Italian silviculture is mainly focused on the production of low-value timber or, even worse, as biomass for energy purposes [3, 4, 6]. Therefore, the material that can be harvested from most Italian forests is not very profitable and far from the application of management models based on advanced mechanisation. The chainsaw, actually, is still the most widely used machine in the sector. Investigations conducted systematically since the 1960s have revealed several critical issues related to the constant and perpetual use of such portable equipment. In particular, continuous and repeated exposure to physical agents such as noise and vibration [20] are at the root of the aetiology of many occupational diseases. In fact, several studies have shown that the amount of noise emitted by chainsaws can exceed 90 dB (A) [2], putting the operator at serious risk of hearing loss [13]. The vibrations that are discharged onto the hand-arm system, in turn, cause irreversible damage to the peripheral circulatory system of the hands (rupture of capillaries), with the onset of Raynoud's syndrome or 'white fingers' disease [14]. There are few works in the literature refering the critical issues related to the emissions of airborne pollutants [19] associated with continuous long-term exposure to machines such as chainsaws. Both temporary and chronic damage resulting from the inhalation of exhaust gases from chainsaws and brush-cutters has so far only been considered in very general terms, or worse, compared to that found in other contests involving the use of hand-guided power tools (lawn mowers, motor-hoes, etc.). The peculiar characteristics of the work carried out with such equipment have not been taken into account, which, for example, favouring considerable operator fatigue [12], increasing the heartbeat and, consequently, accelerating breathing, which can lead to a respiratory rate greater than 60 L per minute. This further aggravates the operator's exposition to airborne

pollutants, which composition is characterised both by the gases produced during combustion, and by the fraction of non-combusted mixture expelled with the latter's residues (approximately 30% of the mixture initially used in two-stroke engines). To address these critical issues, in recent decades, a series of national and EU laws have been enacted to regulate tolerable exposure levels and the prevention tools to be used according to them. Among the most important and up-to-date laws in the sector in Italy is Legislative Decree No. 81 of 9 April 2008 on the 'Consolidation Act on health and safety in the workplace', an extremely innovative and constantly updated provision aimed at reorganising and integrating all the relevant regulations.

The objectives of the present work are:

1. To assess whether the concentration of pollutants contained in chainsaw exhaust gases complies with the limits set by current legislation during operations in a chestnut coppice;
2. To assess the noise emitted by the chainsaw during the utilisation activities of a chestnut coppice.

2 Material and Methods

2.1 Study Site

The experimental trials were carried out between 13 and 20 December 2013 in a chestnut coppice managed with clear-cuts. The experimental area is located in the municipality of Sassano (SA), precisely in the locality of "Gravola", at an altitude of approximately 900–1000 m above sea level. The silvicultural operations surveyed were as follows: Felling (FE), Delimbing (DE) and Bucking (BU).

All tests were carried out under clear sky, weak wind conditions and a temperature of 9 ± 3 °C.

2.2 Chainsaw

Today, the market offers a wide range of chainsaw solutions and models with different power ratings and features. For the experimental tests, a Husqvarna 357xp chainsaw was used, the main technical data of which are shown in the table (Table 1).

A 5% mixture of petrol and synthetic oil was prepared for the experimental tests.

Table 1 Technical data Husqvarna 357 XP chainsaw

Technical data: Husqvarna 357 XP chainsaw	
Sound power level dB (A)	100 dB (A)
Sound pressure level dB (A)	112 dB (A)
Vibration values (handle ant/post m/s^2)	3.9/4.2 m/s^2
Engine displacement (cm^3)	56.5 cm^3
Power (KW/HP)	3.2 kW
Weight (Kg)	5.5 kg
Maximum rotation speed	9600 rpm
Recommended bar length (min–max)	40 cm

2.3 Dosimeter

For the evaluation of the overall sensation resulting from the perception of a complex sound or noise, a Noise sensor TES 1355 dosimeter is used to simulate the response of the human ear. This instrument, which goes by the name of sound pressure level meter (dosimeter), is capable of transforming sound pressure into decibels. A TES 1355 dosimeter consisting of a microphone, preamplifier, frequency-weighting circuit, third octave, RMS circuit, analogue output, integrator circuit and a display system was used for the experimental tests.

2.4 Gas sensor

A MultiRAE PGM-50 plus professional gas detector was used to assess personnel exposure to airborne pollutants in the exhaust gases emitted by the chainsaw. It is a programmable multi-gas monitor that allows continuous real-time monitoring of toxic, oxygen and combustible gases. The instrument detects and records in the data logger the instantaneous concentration of gases in real time in parts per million (ppm) for toxic gases, in volume percentage (%vol) for oxygen and in volume percentage referred to the lower explosive limit (%vol of LEL) for combustible gases.

2.5 Experimental Design and Data Analysis

Noise measurements were carried out during FE, DE, BU operations on a sample of 30 trees. 140 observations were made for each silvicultural operation, making a total of 420 observations. Each silvicultural operation also involved individuals with different diametrical classes, in order to have data relating to the different situations to which the operator is subjected. The dosimeter was mounted directly on the operator during chainsaw cutting operations in order to obtain a good simulation of the stresses

to which the hearing apparatus is subjected. Exhaust gas, i.e. CO, VOC and C_6H_6, sampling was carried out by applying the instrumentation on the operator's belt, using special clips. This method gives acceptable results, since during the movements of the operator, the basic condition required by the standards, i.e. the proximity of the analyser to the worker's mouth, is constant. The instantaneous measurements of the three variables relating to the gas emission were acqured at sampling time of 15-min intervals during each processing phase (FE, DE, BU). Therefore, 8 sets of measurements were carried out for each type of operation. The descriptive statistics for each data set were calculated: maximum values (Vmax), minimum (Vmin), average (μ) and standard deviations (σ) relating to each time interval and each work process. In particular, to estimate the variability of the parameters acquired, the coefficient of variation was:

$$\text{CV}\ (\%) = \frac{\sigma}{|\mu|} \times 100 \tag{1}$$

3 Result and Discussion

The 420 observations made using the TES 1355 sound level meter showed that the limit established by current Italian legislation, set at 85 dB (A), is far exceeded in every silvicultural operation carried out with a chainsaw. The situation becomes particularly critical in the case of large diameters, especially during felling operations, where the highest average values and peaks are recorded. The table below shows the comparison between the data obtained from the analysis of variance for each operation (Table 2).

Figures 1a, b and c, graphically show the respective average values of CO, VOC and C_6H_6 detected in each of the 8 times intervals and for each process, using the MultiRAE PGM-50 plus professional gas detector. Each figure also shows the emission limits established by law. The graphs show considerable asymmetries especially

Table 2 Average noise for different operations

		Mean	Variance
Felling	Diameter 5 cm	86,393	159,118
	Diameter 7 cm	88,379	162,097
	Diameter 9 cm	90,576	169,589
Delimbing	Diameter 12 cm	90,796	187,655
	Diameter 16 cm	92,256	190,733
	Diameter 18 cm	94,932	196,136
Bucking	Diameter 10 cm	90,735	154,147
	Diameter 15 cm	94,344	177,325
	Diameter 20 cm	101,541	204,845

for the emissions in the FE phase. Table 3 shows the mean values of the maxima detected in each of the 8 repeated measurements and the mean values of the same measurements, with the relative standard deviations and relative CVs. To evaluate the data variability, the average of the maximum values, although more subject to the presence of momentary peaks, is more reliable, since during the 15 min of constant detection by the instrumentation the chainsaw condition often occurs with engine running but not working. In accordance with what has just been highlighted, the comparison between the coefficients of variation revealed relatively low values for the coefficients of variation calculated on the maximum values and high values for those calculated on average values, as shown in the table below. However, the table shows a greater variability of the coefficient of variation for delimbing operations compared to the other two cases. This can be correlated to the great diameter variability that can be found between the branches of the same tree. Analyzing the coefficients of variation calculated on the average values, they are generally higher, with the particular exception of CO emissions during BU operations (CV = 7%).

Subsequently, a comparison was made between the average values recorded and the limits established by international legislation (Table 4). From the investigation it is possible to state that these limits are always disregarded in relation to the maximum

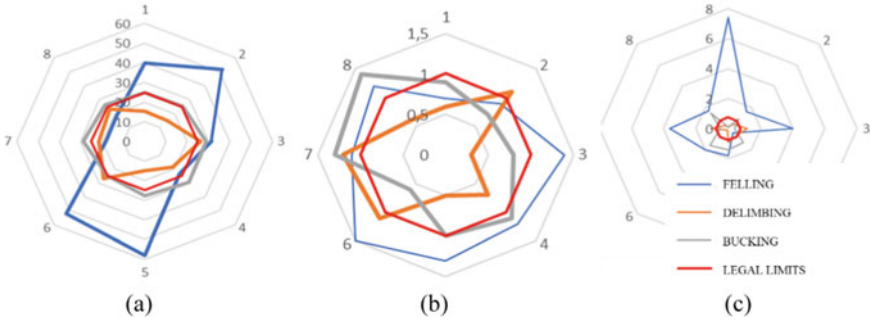

Fig. 1 Average CO (a), VOC (b) and C_6H_6 (c) emission in each reference interval and for each machining operation

Table 3 Data on gaseous emissions during wood processing

	Felling – FE (ppm)			Delimbing – DE (ppm)			Bucking – BU (ppm)		
	CO	VOC	C6 H6	CO	VOC	C6 H6	CO	VOC	C6 H6
MED (Max)	135.96	17.28	2.51	33.09	2.65	1.13	76.26	15.24	1.73
SD (Max)	25.75	4.63	0.48	11.15	1.07	0.21	11.31	4.12	0.55
CV (Max)	**0.19**	**0.27**	**0.19**	**0.34**	**0.40**	**0.18**	**0.15**	**0.27**	**0.32**
MED(Vm)	36.66	2.81	1.16	20.21	0.60	0.76	27.08	0.96	0.98
SD (Vm)	16.09	2.18	0.26	5.02	0.44	0.33	1.92	0.57	0.28
CV (Vm)	**0.44**	**0.78**	**0.22**	**0.25**	**0.73**	**0.43**	**0.07**	**0.59**	**0.29**

Table 4 Comparison between gaseous emissions measured in the field during wood processing and the limits permitted by law

	Felling – FE (ppm)			Delimbing – DE (ppm)			Bucking – BU (ppm)		
	CO	VOC	C6 H6	CO	VOC	C6 H6	CO	VOC	C6 H6
Leg_Lim	25	0.75	1	25	0.75	1	25	0.75	1
$\frac{\text{MED(Max)}}{Leg\_Lim}$	5.44	23.03	2.51	1.32	3.53	1.13	3.05	20.3	1.73
$\frac{\text{MED(Vm)}}{Leg\_Lim}$	1.47	3.75	1.16	0.81	0.8	0.76	1.08	1.28	0.98

values recorded during the three different operations. However, based on the average values recorded, the situation appears less critical. This data is particularly encouraging, considering that during the various operations the maximum values are reached infrequently. In particular, the BU operations emit below-threshold values on average, the BU operations settle in values slightly higher than the threshold while the FE operations are the most critical, determining values well beyond the threshold, above all with reference to the VOC. What has been stated suggests the use of PPE for the protection of the respiratory system especially in this phase, which can be considered particularly risky for the health and safety of the operators. In Table 4, from the comparison between the average of the maximum values and the average values acquired during the operations in the field, it is notable the presence of high peaks of VOC emissions during the three operations. The data becomes even more alarming for the FE operations, where the maximum values recorded are almost 16 times higher than the average values. From the analysis of the graphs in Fig. 1 and the comparison between the averages of the measured values and the maximum values, it follows that:

1. The three operations, in accordance with what was found by Neri et al. [19] and Bernini [1], from the point of view of the effort required of the gear, can be characterized differently according to the CO and C_6H_6 emissions:
   a. **Felling:** during this operation the chainsaw is called upon to make great efforts, this can be correlated with the high emissions of CO and C_6H_6, however important time intervals are recorded within the same operation, also to make the operator catch his breath more susceptible to fatigue;
   b. **Cutting:** during this operation the chainsaw is called to express medium efforts, this can be correlated with sufficiently high emissions of CO and C_6H_6, however the time intervals in which the tool is on but not operating at cutting in the measurement range of 15 min are less than what happens in the blast chilling phase.
   c. **Delimbing:** during this operation the tool is called upon to exert small efforts, releasing moderate doses of CO and C_6H_6 into the environment, moreover the intervals in which the engine is running but not operating in the 15 min of detection are extremely reduced if compared to the operations pre-teeth.

2. The chainsaw, in accordance with Gallo [11] and Kovac [15] produces high VOC emissions when it is switched on but not operating at the cut. By examining what happens during logging operations, it can be stated that:
    a. The maximum emissions recorded during the two operations are similar (17.28 ppm for abatement and 15.24 ppm for bucking), being 1.3 times higher in the abatement phase;
    b. The average emissions recorded during the two operations are particularly different (2.81 ppm for abatement and 0.96 ppm for bucking), being 2.9 times higher in the abatement phase;
    c. The high risk of exposure occurs in the abatement phase, when VOC emissions are particularly higher than the legal limits;
    d. The least risk situation, on the other hand, occurs during demilling operations when, as the chainsaw's non-working intervals are minimal, low VOC emissions are recorded, both considering the maximum (2.65 ppm) and average (0.60 ppm) values.

4 Conclusions

The analysis of the noise level of silvicultural operations highlights a high risk for operators in the sector and the constant exceeding of the limits envisaged by the regulations in force. However, the risk factors can be easily controlled through the use of PPE. The risk assessment of worker exposure to airborne pollutants is alarming. After calculating personal exposure on the basis of the measurements taken during the samplings, it appears that, according to current regulations, only 7 out of 25 construction sites present a risk that can be described as moderate for CO emissions. In all other samplings, the chemical risk from inhaling CO, VOCs and benzene was found to be non-moderate. As far as carbon monoxide emissions are concerned, the activity that presents the greatest problems is FE. Statistical analysis of VOC and C_6H_6 highlighted more critical issues, in fact high VOC emissions were detected in the case of chainsaws not in operation and high C_6H_6 when the machinery is working intensely. This criticality is being investigated through further measurements in different contexts. Finally, the introduction also at professional level of electric battery power chainsaw will reduce and probably solve in few years most of the problems which have been highlighted by the study.

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