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Air-Borne Particle Size Distribution of Wood Dust Emitted during Small Scale Forestry Operations

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Abstract:

Practices such as tree felling, pruning, logging and chipping wood can produce significant amount of wood particles that can be inhaled by agricultural and forestry workers, triggering an important risk to the health of workers. Especially finest fractions of dust, less than 4 µm in diameter (the respirable fraction) may cause respiratory and dermal diseases, until to the risk of developing nose and sinus adenocancer. The aim of this work was to assess the particle size distribution of wood dust produced during chainsaw operations. In two separate trials (July and December), wood logs of three different species (*Eucalyptus* sp., *Pinus radiata* and *Quercus cerris*) were employed in cutting tests. Two chainsaws, one electric powered by batteries and one endothermic, were employed. To characterize the particle size distribution, samplings were carried out with a dust particle counter placed in the area surrounding the tests' site. Results showed that the dust was characterized by a major fraction of fine particles around 0.3 µm (72% of the particles from 0.3 to 10 µm). The chainsaw with endothermic engine produced more fine dust of the electric one. Obtained amounts of inhalable wood dust were very variable in values, however attention should be paid to the exposure to wood dust considering potential risks, especially in case of long times of exposure.

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INTRODUCTION

Multiple possible sources can generate inhalable inorganic or organic dust during different agroforestry practices and workers are routinely exposed to high levels of airborne dust particles that have been linked to adverse health outcomes. For example, soil particles can be generated during soil tillage [1, 2], during harvesting [3] or it can be raised from not paved roads adjacent to fields and houses [4]. Other sources include the abrasion dust from seeds coated with pesticides which are spread during sowing operations [5], powdery pesticides products [6] including sulfur to combat fungal diseases [7], storage of agricultural crops and livestock rearing, especially in broiler and chicken farms [8].

Wood is also a significant dust source. Practices such as tree felling, pruning and chipping can produce wood dust that can be and inhaled by agricultural and forestry workers.

The term “dust” generally refers to solid particles whose size, measured in microns (µm), ranges from 1 to 100 µm. Depending on its size, dust is deposited either in the nasal cavity (< 100 µm), or in the respiratory tract below the larynx (< 10 µm), or in the alveolar region of the lungs (< 4 µm).

Exposure to wood dust may cause respiratory and dermal symptoms and diseases. The most serious problem arising from wood dust exposure is the risk of developing cancer, mainly nose and sinus adenocancer [9]. It has been estimated that 150,000 workers of the forestry sector can be exposed to wood dust in Europe (25 countries) [10].

The International Agency for Research on Cancer (IARC) categorized dust from wood as carcinogenic for humans [11]. The inhalation of wood dust depends on particle fraction size, on movement of air around the body and on respiratory rate. The greatest danger to respiratory organs is the respirable component with a particle size of less than 10 µm [12].

The European Directive 2004/37 establishes an occupational exposure limit (OEL) of 5 mg m^{-3} measured over a period of 8 hours as an inhalable fraction. The Scientific Commission for Occupational Exposure Limits (SCOEL) of the European Union indicates that occupational exposures to wood powders above 0.5 mg m^{-3} induce pulmonary effects and should therefore be avoided. SCOEL in 2003 adopted an OEL of 1-1.5 mg m^{-3}. In the U.S.A. both the ACGIH (American Conference of Governmental Industrial Hygienists) and the NIOSH (National Institute for Occupational Safety and Health) have adopted a more restrictive limit of 1 mg m^{-3}. The Directive 2004/37 has been amended by Directive 2017/2398, to be implemented by 17 January 2020, lowering the limit to 2 mg m^{-3} with a transition of five years, to 17 January 2023 when the limit was set to 3 mg m^{-3}.

The occupational exposure to wood dust is largely investigated during operations carried out indoor, mainly related to the sawing of fresh and stored wood and in the furniture industry. However, exposure can occur also during practices carried out in open air. Some studies have addressed forest operators’ exposure, mainly taking into account the respirable wood dust fraction in chainsaw operation [9, 13], pruning [14] or chipping operation [15-17]. However, data about the size distribution of particles are rather scarce.

The aim of this work was to assess the particle size distribution of wood dust produced during cutting chainsaw operations.

MATERIAL AND METHODS

Two light chainsaws were employed in the cross-cutting tests: an endothermic one and an electric one powered by lithium batteries (Table **1**).

In the trials of July (summer conditions), fresh wood logs of two different species (*Eucalyptus* sp. and *Pinus radiata*), 2.5 m long, with a diameter of 15-20 cm, were employed. Dry Pinus logs were also employed. In December (winter conditions), the tests were carried out cutting logs of *Quercus cerris* (about 20 cm of diameter) with only the endothermic chainsaw (Table **2**). In each test 100 cuts were carried out (Figure **1**).

Wood humidity was determined by re-weighing samples of wood after drying in a ventilated stove until constant weight.

In all tests, two different oils have been used to lubricate the cutting chain, a refined olive pomace oil and a mineral biodegradable oil (Bioplus, Stihl). At the beginning of the trials, a new cutting chain was mounted on the chainsaws. The cutting was carried by a professional operator who continuously cut wood disks during the test.

Table 1: Characteristics of the Chainsaws Employed in the Tests

Brand	Pellenc	Stihl
Model	Selion C21HD	MS 201TC
Engine Displacement (cm^3)	45*	35.2
Power (kW)	2	1.8
Max recommended engine speed (min^{-1})	6.200	10.500
Fuel reservoir volume (L)	-	0.30
Oil reservoir volume (L)	0.25	0.22
Oil pump type	Adjust. flow	Adjust. flow
Chain pitch (mm)	6.35	9.5
Guide bar length (mm)	280	350
Sound pressure (A weighted), dB(A)	85	100 ± 2.5
Sound power (A weighted), dB(A)	100	113 ± 2.5
Vibration front/rear (mm s^{-2})	2.5 / 2.5	3.5 / 3.1
Mass without cutting group (kg)	2.55	3.7

* heat engine equivalente.

Figure 1: Cross-cutting tests during summer trials.

The measurements were conducted using an ARW-9880 dust particle counter (Shenzhen Ever-best Machinery Industry Co., Ltd, China), to determine the number of dust particles in six classes of diameter size (0.3, 0.5, 1.0, 2.5, 5.0, and 10 µm). The instrument, operating at a flow rate of 2.83 L min^{-1}, was placed at about 10 m from the working point in July, and at about 2 m in December. Data acquisition lasted the entire duration of the test, with a frequency of integration equal to 60 s.

Micrometeorological conditions were continuously monitored during the trials with a portable weather station (Kestrel 4500). The tests have been conducted in the absence of wind.

The average total particle number during the different treatments was analyzed with an ANOVA (Analysis of variance) in each trial (July and December), following the experimental design. In July the test followed a tri-factorial design, with lubricant, chainsaw and wood as factors; in December the ANOVA examined only the

Table 2: Scheme of the Tests and Micrometeorological Conditions

Date	Chainsaw	Lubricant	Wood	Wood humidity (%)	Air Temperature (°C)	Air Relative Humidity (%)
July	Electric	Pomace	Eucalyptus	55.1	41.0	30.1
	Endothermic	Pomace	Eucalyptus	57.1	41.4	32.7
	Endothermic	Pomace	Pine (dry)	14.5	40.7	34.7
	Electric	Mineral	Eucalyptus	53.7	44.8	27.4
	Endothermic	Mineral	Eucalyptus	56.2	38.8	37.6
	Electric	Mineral	Pine	48.0	42.3	30.8
	Endothermic	Mineral	Pine	48.6	31.1	52.4
December	Endothermic	Pomace	Turkey oak	33.8	10.4	71.1
	Endothermic	Mineral	Turkey oak	33.8	12.8	57.5

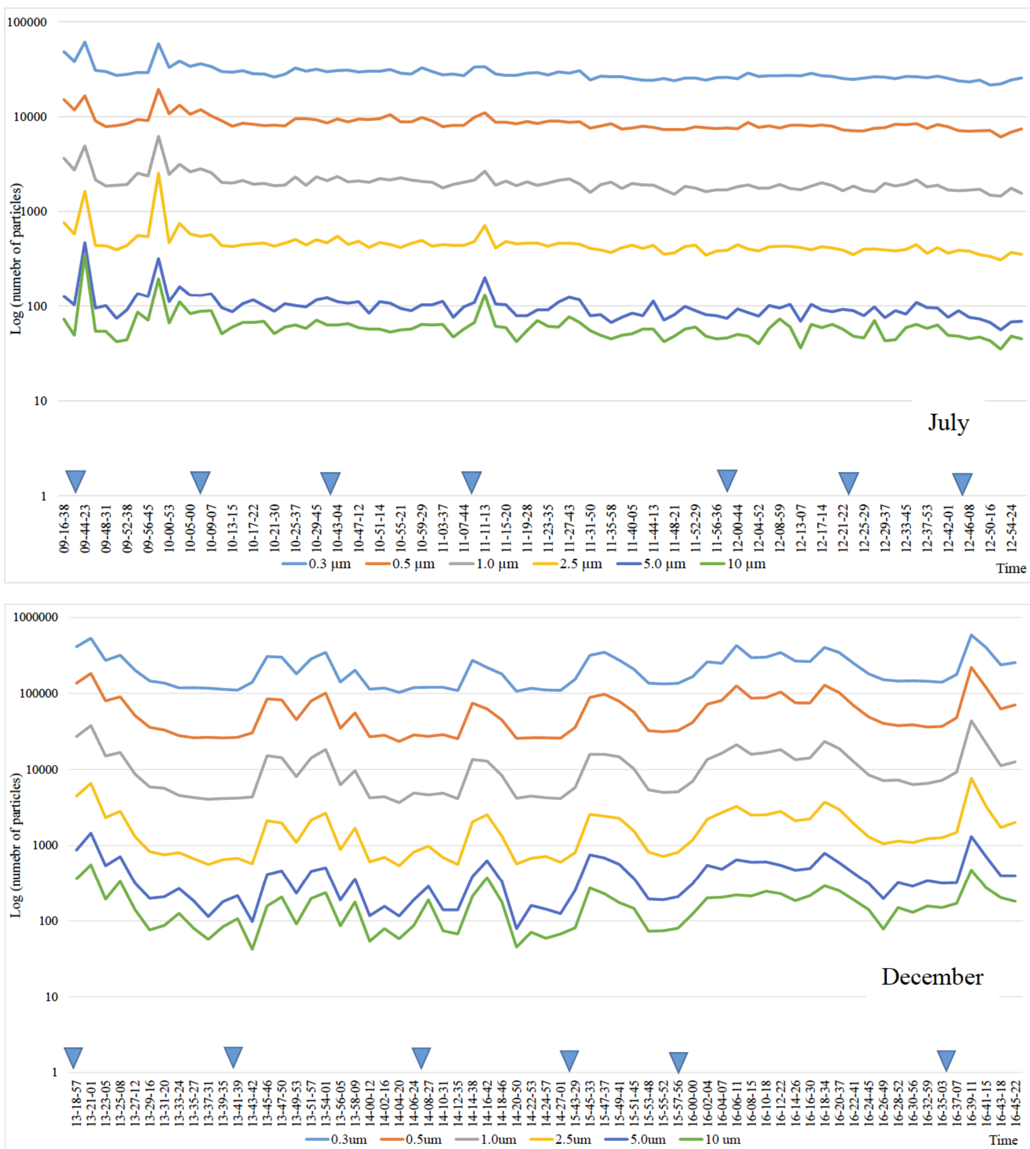

Figure 2: Logarithm of number of particles of wood dust in each size class during the test of July and December. The marks on the x axes are referred to the starting time of each cutting test.

Table 3: Percentage Distribution of Particle Size Classes in the Experimental Conditions

Test	0.3 µm	0.5 µm	1.0 µm	10 µm	2.5 µm	5.0 µm	Number of measurements
Electric chainsaw	**72.1%**	**21.4%**	**5.0%**	**0.1%**	**1.1%**	**0.2%**	**112**
Eucalyptus	72.1%	21.4%	5.1%	0.1%	1.1%	0.2%	77
Pine	72.3%	21.4%	4.9%	0.1%	1.1%	0.2%	35
Petrol chainsaw	**73.8%**	**21.0%**	**4.2%**	**0.1%**	**0.8%**	**0.2%**	**448**
Turkey oak (December test)	74.8%	20.7%	3.7%	0.1%	0.6%	0.1%	294
Eucalyptus	71.8%	21.5%	5.1%	0.2%	1.2%	0.3%	84
Pine	72.9%	20.1%	5.2%	0.2%	1.3%	0.3%	21
Pine (dry)	71.2%	22.2%	5.1%	0.1%	1.1%	0.2%	49

factor lubricant. The statistical software R [18] was employed to perform the analysis.

RESULTS

The number of particles in each size class was recorded during the entire test, with a frequency of acquisition equal to 60 s. These values are showed for each trial carried out in Figure **2** where the graph shows dust concentration peaks in connection with each cutting operation, especially in the "winter" trial, when the instrument was placed closer to the cutting point. The different position of the instrument likely also influenced the total amount of particles counted in December compared to July.

To compare the different treatments, the values of particles number recorded during the time of each single test were computed and analyzed, while the data acquired during the pauses between the tests were discarded.

Table **3** shows the percentage composition of dust in terms of diameter size recorded in all tests. The largest part of the particles (73.4% in average) was very fine, with an average diameter around 0.3 µm.

In general, the size distribution pattern is similar both in different woods and different chainsaws. However, an increase in the finest fraction (74.8%) occurred in Turkey oak wood and using the endothermic chainsaw

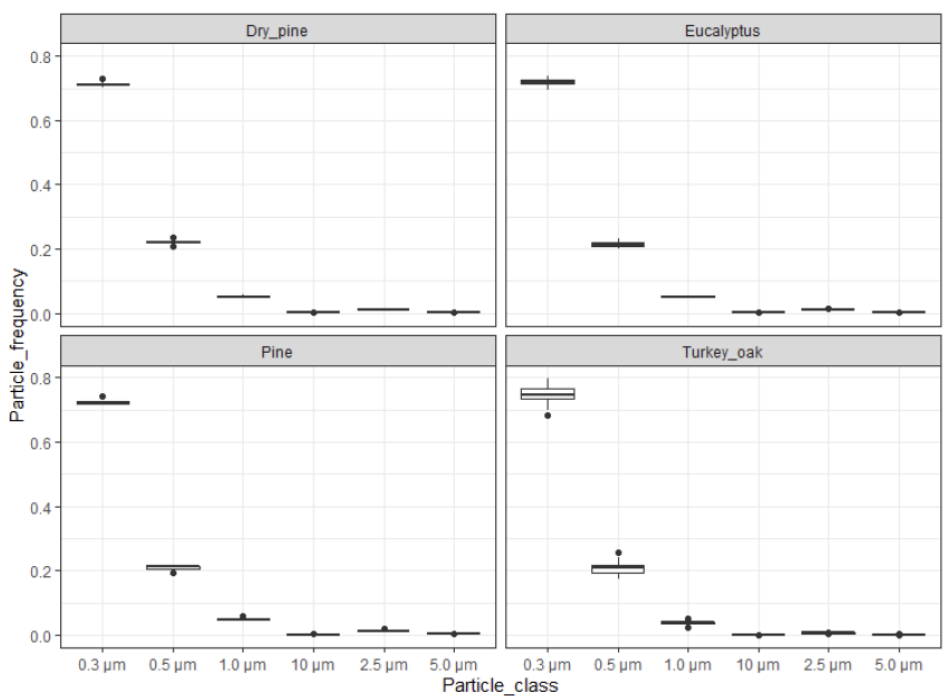

Figure 3: Percentage composition of particles size dust by different tested woods.

Table 4: Anova Responses for the Average Total Particle Number in the Different Treatments

Trial	Treatment	Degrees of freedom	F value	Pr(>F)	Significance
December	Lubricant	1	3.7302	0.06055	
	Residuals	40			
July	Lubricant	1	0.6828	0.41495	
	Chainsaw	1	54.6091	>0.001	***
	Wood	2	3.4077	0.04594	*
	Lubricant × wood	1	0.8045	0.37668	
	Chainsaw × wood	1	2.4527	0.12747	
	Residuals	31			

(Figure **3**). The patterns were comparable also evaluating the tests carried out employing the two oils used for lubrication. The variability in the number of samples analyzes (Table **3**) was due to the duration of each test and to the different designs of the experiments.

The data of total particle number were analyzed to assess the influence of the different treatments on the dust production (Table **4**). In the summer trial, a significative difference between electric and endothermic chainsaw occurred, with the last one producing around 20% more particles than the electric one. A minor difference (but still significative) was caused by the type of wood cut, with about 10% of dust more than average was produced cutting the fresh pine.

In all tests (July and December) no significant differences were found in the composition of the powder related to the oil used (Table **4**).

DISCUSSION

Wood cutting with chainsaws remains a common operation in forestry, even if full mechanization of harvesting operations is expanding [19]. Furthermore, in small scale operations and in urban forestry maintenance, the chainsaw is certainly the tool most frequently employed. However, this equipment poses different safety issues during the use [20], including the risk of being cut by the chainsaw chain, the exposure to noise, vibrations and exhaust gas from the endothermic engines and least, but not the last, the production of fine wood particles that can be inhaled by the workers.

The focus of this work was to investigate particle size, a point that is crucial because fine particulate matter is the fraction of dust most dangerous to health. However, data about the size distribution of particles are rather scarce, and very few studies have addressed forest operators' exposure during operations in open air. Moreover, in some trials, we tested an electrical equipment, because these tools are becoming common in small scale forestry operations, for pruning and in urban forestry maintenance. In fact, recently the use of electrically powered equipment is growing, especially thanks to the evolution of the battery sector [21,22]. These equipment are also chosen because they can partially reduce some risks, such as noise and exposure to exhaust gases, and in general are more ergonomic.

In this work we studied the composition of dust in terms of size particle distribution during cross cutting of different woods, in different climatic conditions and using two light chainsaws, one electric and one conventional motorized. The cutting tests were carried out in open air, with a very light wind, simulating a normal operation of cross cutting of wood logs. However, a limitation of this study was that in the two experiments, the investigated factors (wood and chainsaws) were not the same and a slightly different experimental design was chosen. This was due to the prevailing desire to carry out tests in different operative and real working conditions, expanding the case studies.

The wood dust produced during the cutting tests showed a prevailing percentage of particles (more than two third of the total dust) with an average diameter around 0.3 μm. This fraction of powder can reach the lung alveoli, penetrate in the blood stream, and incite serious chronic diseases.

In the July tests, it was observed that using the endothermic chainsaw, both the finest fraction of dust and the total number of particles increased. One potential reason for this is that the electric chainsaw engine has a lower velocity compared to the endothermic engine, and thus, a slower moving chainsaw chain that produces less particle.

Contrary to expectations, this study did not find a significant effect on particle size composition in relation to the micrometeorological conditions (summer and winter tests), even if this point is only speculative. In fact, in the two experiments, the test factors were different, and the statistical analyses were kept separated. It can only be observed that in the winter test a small percentage of very fine particle was produced and this can be likely due to the type of wood (oak) and not to the environmental conditions, also because oak wood is known as capable of generate higher dust concentrations, as early reported [23].

CONCLUSIONS

- Wood cutting can produce major amounts of very fine particles, potentially harmful for human healthy.
- When air-borne particles values exceeded the European legal threshold of concentration the operator should protect himself wearing a proper PPE (personal protective equipment), especially in case of long times of exposure.
- The size distribution and the amount of dust is affected especially by the type of chainsaw, being the endothermic one the equipment that produces a larger quantity of particles.

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