Dust Exposure of Operators During Citrus Orchard Cultivation

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Abstract
This study is focused on operator's dust exposure during some cultural operations: soil tillage, fertilisation, and pruning trituration. Soil tillage was performed by using a disc harrow, a tooth harrow, and a rototiller, fertilisation by using a centrifugal fertiliser, and pruning trituration by using a pruning triturator. Moreover, tractors equipped or not with cab were used. Dust was measured by using a portable particle dust monitor, whose operating principle lies in light scattering, and results were expressed as count per minute (cpm). They can be converted in mg/m^3 by using the standard calibration factor (1 cpm = 0.001 mg/m^3) or by carrying out parallel gravimetric measurements.
During soil tillage and fertilisation, the experiments showed a significant reduction (from 124 to 37 cpm, less than a third) in the exposure when working with the tractor equipped with cab. The highest exposure was measured during pruning trituration (1825 cpm). Assuming the standard calibration factor, these values are lower than the ACIGH exposure limits, but STEL values over 15 minute when working with pruning triturator without cab are near to those established by ACGIH.

Keywords: safety, soil tillage, fertilisation, pruning trituration

Introduction
Although many cultural operations in citrus orchards have been mechanised since a long time by using tractors and operating machines, risks for the operators' safety are still present. Among this, it may be cited dust, volatile organic compound (VOC), noise and whole body vibration exposures. Dust exposure may occur, as an example, during soil tillage or pruning crushing, or when fertilisers or dusters are used, while VOC exposure is due, for example, to the engines' exhaust or the pesticides sprayed during treatments of trees or soil. Noise and vibration exposure is always present when tractors are used.

In this study, the attention is focused on dust exposure, taking into consideration some cultural operations: soil tillage, fertilisation, and pruning trituration.

Similar studies have been conducted on confined spaces as greenhouses to evaluate the re-entry times (Siebers and Mattusch, 1996; Carrara *et al*., 2005; Conte *et al*., 2008; Gambino *et al*., 2008), nurseries (Madsen *et al*., 2009), farm animal houses (Hartung and Schulz, 2008; Costa and Guarino, 2007), during grain handling, when the risk to breathe mycotoxins is also present (Geng, 2008), industrial companies as pasta factories (Bianchi *et al*., 2008) or wood factories (Biondi *et al*., 2002).

Some studies in open filed have concerned the mechanised harvesting of hazelnuts (Cecchini et al., 2005; Monarca et al., 2008), as well as the use of motorised handheld machines as chainsaws and portable brush-cutters, which expel the exhausts near the operator

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(Monarca et al., 2005).

During some cultural operations in citrus orchards as fertilisation, soil tillage with rototillers (widespread in many hilly areas), or pruning trituration, due to the limited space between the rows that prevent using tractors equipped with cab, the risk of dust exposure could be quite high. This research is a first approach to afford the problem, that will be expanded in the future by other measurement sessions in different working conditions.

Materials and Methods

Dust exposure was measured during soil tillage with a tooth harrow, a disc harrow, and a rototiller, during pruning trituration with a pruning triturator, and during fertilisation with a centrifugal fertiliser. Soil tillage and fertilisation were carried out in one citrus orchard and pruning trituration in another one, with two tree layout: 4 m × 6 m and 4 m × 8 m. Moreover, tractors equipped or not with cab were used (Tab. 1 and Fig. 1).

Table 1. Cultural operations and machinery involved in the experimental tests.

Cultural operations	Operating machines	Tractors	
Soil tillage	Tooth harrow	33 kW, tracked, without cab	59 kW, wheeled, with cab
	Disk harrow	33 kW, tracked, without cab	59 kW, wheeled, with cab
	Rototiller		
Fertilisation	Centrifugal fertiliser	33 kW, tracked, without cab	59 kW, wheeled, with cab
Pruning trituration	Pruning triturator	55 kW, wheeled, without cab	

Figure 1. Tractors and operating machines used for the experimental tests (from top to bottom, from left to right): wheeled tractor with cab; tracked tractor; rototiller; wheeled tractor without cab; disk harrow; tooth harrow; fertiliser; pruning triturator.

Dust was measured by using a portable particle dust monitor, the model 3431 by Kanomax, whose main characteristics are shown in Table 2. Its operating principle lies in light scattering: when a laser hits particle matter, light scattering occurs. The dust monitor detector unit (photo diode) collects the amount of scattered light, converts it into electrical

signal, and adds it as count value (count per minute: cpm). Given the pump flow rate of 1 dm^3/minute, it follows that 1 cpm is equivalent to 1 count per cubic decimetre. If density of particle matter is known, count can be converted to mass concentration (mg/m^3) in proportion to the scattering light, otherwise gravimetric sampling is required. In this study the standard factory calibration is used, for which 1 cpm = 0.001 mg/m^3 for 0.3 µm stearic acid particles. Applications for light scattering dust monitor include indoor air quality investigations, point source monitoring, and personal exposure monitoring.

Table 2. Main characteristics of the 3431 digital particle counter by Kanomax.

Measuring Method	Light Scattering Method
Particle Size Range	0.1–10 µm
Measuring Range	1–9999 count per minute (cpm)
Pump Flow Rate	1 dm^3/minute
Accuracy	±10% of reading ±1 cpm
Measuring Time	1 minute / 3 minutes / 10 minutes with built-in timer, and continuous mode
Light Source	Laser diode
Detector	Photo diode
Display	4-digit LCD, dust count value (cpm), relative mass concentration value
Output	Analog output, instant value 0–4000 cpm = 0–2.5 V
Power Supply	AC 100 V adapter and dry cell batteries (6 × AA batteries)
Dimensions	162 × 62 × 100 mm
Weight	1 kg, not including batteries

Figure 2. Dust monitor and data logger unit.

Figure 3. Positioning of the dust monitor during the experimental tests.

As the device is lacking in datalogging capability, to monitor continuously the particle concentration its analog output was connected to an external data logger. The management software HOBOware Pro allows for the main graphical and numerical analyses, as well as for the raw data export. A picture of both dust monitor and data logger unit is shown in Figure 2. Measurement sessions ranged from about 6 up to 41 minutes. During measurements, the dust monitor was hung to the operator's neck by means of a suitable shoulder belt (Fig. 3) or

placed inside a pocket of a jacket worn by the operator. The air sampling point was situated at about 30 cm from the respiratory tract. Monitoring was carried out continuously with a sampling time of one second and average values were calculated at every minute for each cultural operation. All calculations and graphical representations were carried out by using the open source software R.

Results and Discussions

Figures 4 and 5 report the cpm values (average values at every minute) for each cultural operation. Whole average values and standard deviation among the minutes are reported in Figure 6.

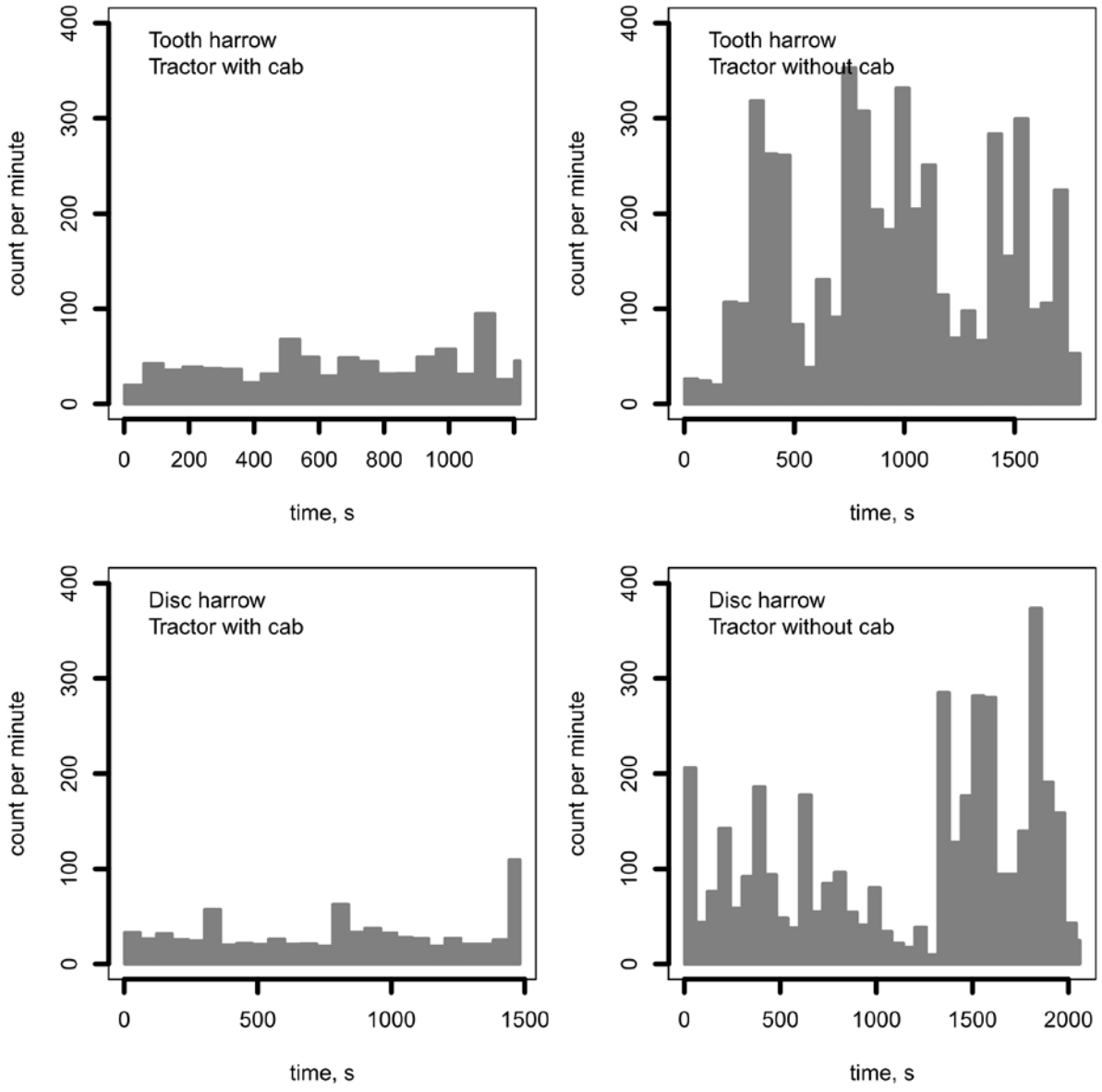

Figure 4. Dust concentration (average values at every minute).

When considering soil tillage and fertilisation, both operations performed in the same citrus grove, the graphs show a significant reduction in the cpm values when working with the

tractor equipped with cab. In fact, the average cpm value was 37 when using the tractor equipped with cab (41 cpm for the tooth harrow, 31 cpm for the disc harrow, and 37 cpm for the fertiliser) and more than three times as much when working with the tractor without cab (163 cpm for the tooth harrow, 115 cpm for the disc harrow, and 94 cpm for the fertiliser). The highest average value (174 cpm), as expected, was measured when working with the rototiller, whose operating tools are very near to the operator.

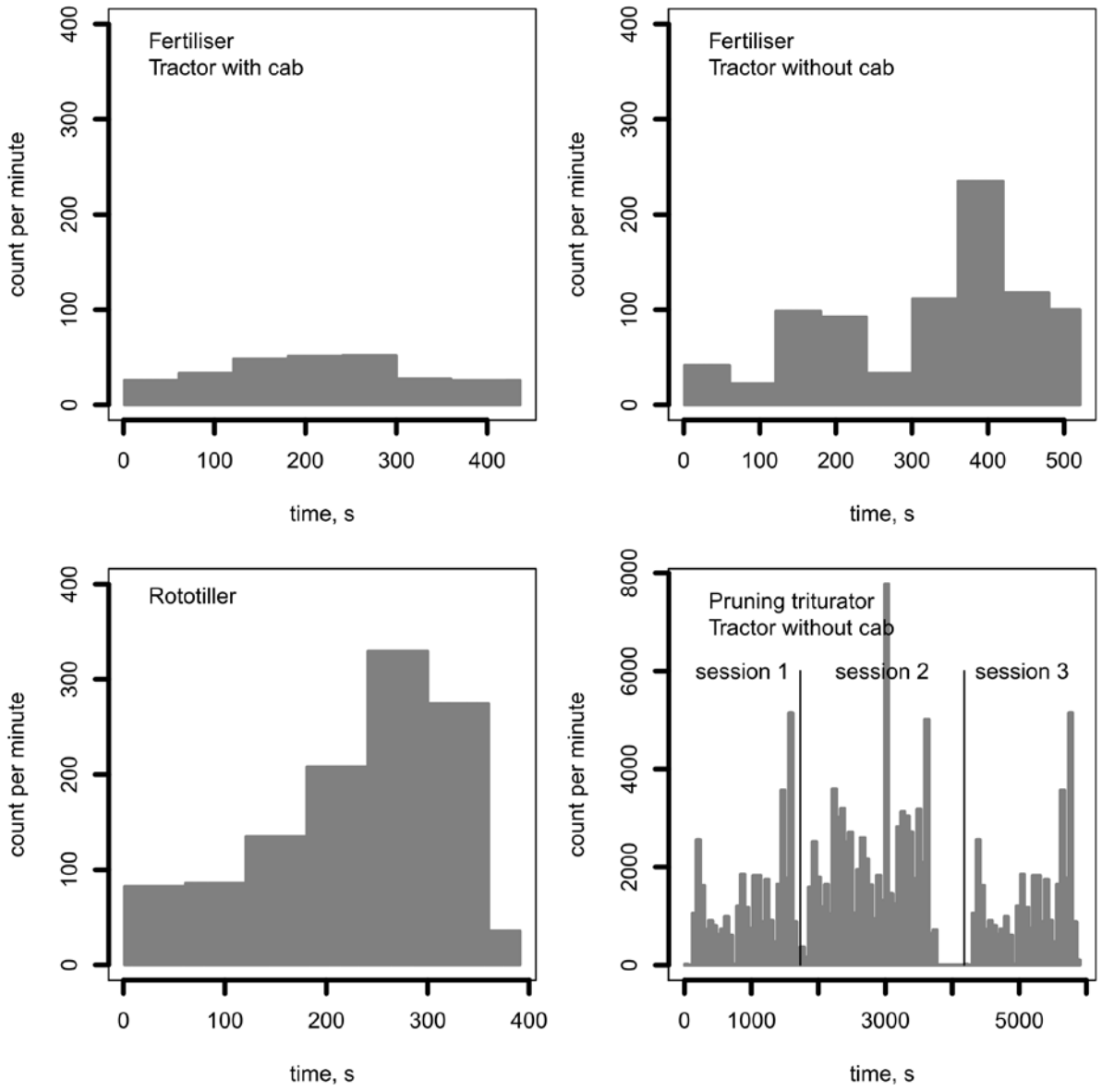

Figure 5. Dust concentration (average values at every minute).

Pruning trituration, performed in a different citrus orchard, was characterised by a much high dust production. The average cpm values ranged from 332 to 1825 for the three replicates. This was due both to the mode of functioning of the operating machine (the high speed rotating tools triturate pruning and whip up dust) and to the different soil characteristics (in the first citrus orchard the soil was partly covered with grass).

In order to evaluate the exposure, cpm values have to be converted in mg/m^3: assuming

the standard factory calibration for which 1 cpm = 0.001 mg/m^3 (more precise determinations require parallel gravimetric measurements), it follows that average dust concentration ranges from 31 (disc harrow, tractor with cab) to 1825 μg/m^3 (pruning triturator, tractor without cab).

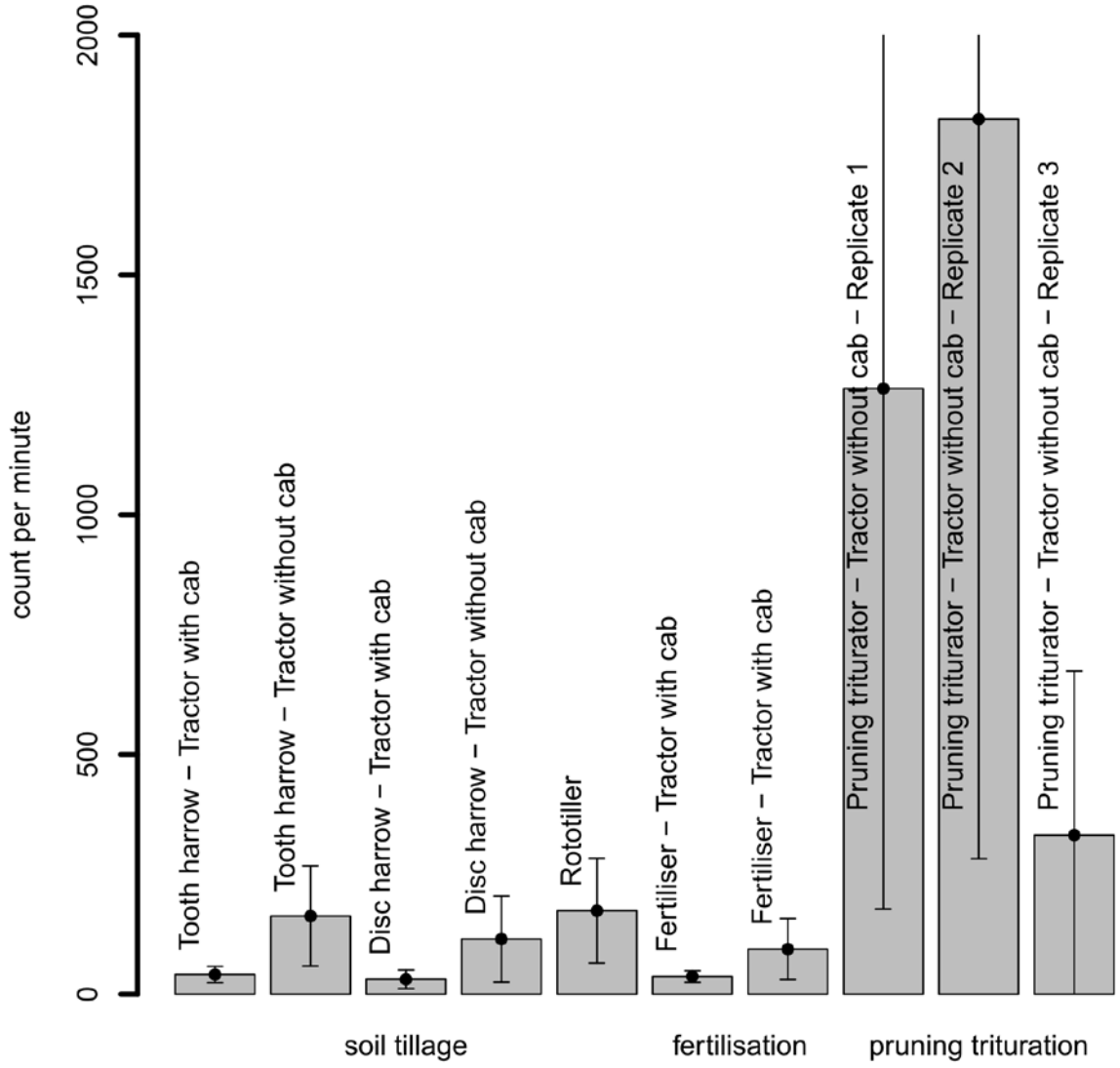

Figure 6. Dust concentration (average values and standard deviations for each cultural operation).

Threshold limits values (TLV), recommended exposure limits (REL), or permissible exposure limits (PEL), are fixed and annually updated by Organisms like ACIGH (American Conference of Governmental Industrial Hygienists), NIOSH (National Institute for Occupational Safety and Health), or OSHA (Occupational Safety and Health Administration), respectively. There are three categories of limits. The NIOSH defines:

1. Time-weighted average (TWA): time-weighted average concentration for up to a 10-hour workday during a 40-hour workweek;
2. Short-term exposure limit (STEL): unless noted otherwise, the STEL is a 15-minute TWA exposure that should not be exceeded at any time during a workday;
3. Ceiling REL: unless noted otherwise, the ceiling value should not be exceeded at any

time.

ACGIH and OSHA provide similar definitions.

The TLV-TWA limits established by ACGIH over an 8 hours exposure time and for (insoluble) particles not otherwise classified (PNOC), are (2007) 3 mg/m^3 for respirable dust (particle diameter from 0.5 to 5 μm) and 10 mg/m^3 for inhalable dust (particle diameter from 5 to 10 μm). In the present study, all the average values computed are lower than these limits. Only the tests with the pruning triturator are characterised by peak and STEL values (Tab. 3) that come near to 3 mg/m^3.

Table 3. STEL ranges (cpm or μg/m^3) measured during the experimental tests.

	Tractor	
Operating machine	With cab	Without cab
Tooth harrow	38–45	155–211
Disc harrow	27–32	59–154
Rototiller		174
Fertiliser	37	94
Pruning triturator		269–2665

The low values measured during soil tillage are to be related to the soil characteristics, partly covered with grass, so, continuing the researches, other different working conditions—different soil status and composition, lower humidity, other operating machines and different working time—will have to be investigated.

Conclusions

The study, even if preliminary, allows for some interesting considerations:

- Average values of dust concentration during the experimental tests were quite low and under the threshold limit values established by the ACGIH;
- Cab was efficient in reducing dust exposure during soil tillage: on average, dust concentration when working with tractors equipped with cab was lower than a third of that measured when working without cab;
- Pruning trituration produced much higher dust concentration values. When performed by using tractors without cab, the STEL values were near to those established by ACGIH, so in different working conditions (different pruning density, different operating machine features, different soil characteristics), to exceed limits have to be expected; consequently, during this activity, a tractor with cab would be used or proper PPE would be wore;
- Further studies are necessary to investigate different working conditions so to prepare a complete database useful to assess the real risk of operator's dust exposure in citrus fruit sector.

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