A Prototype of Self-Propelled Sprayer to Reduce Operator Exposure in Greenhouse Treatment

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Abstract

This paper reports the results of some trials aimed at measuring the dermal operator exposure during spray applications to full developed tomato plants, comparing a conventional handheld spray lance and a prototype of self-propelled sprayer suitably designed to properly work in greenhouses.

The spray lance was 0.97 m long, with 4 steel nozzles 0.21 m spaced, suited to spray plants up to 3 m high. The prototype of sprayer consisted of a little tracked tractor powered by a gasoline engine with continuous power of 2.6 kW at 3000 rpm, carrying a 120 L main tank, a volumetric pump, and two vertical spray booms 1.5 m long, each with four nozzles.

Dermal exposure was assessed by means of the spectrophotometric technique: delivering a mixture containing 2% of food dye Red Poinceau as tracer, the deposit on the protective personal equipment worn by the operator was calculated.

The results showed a large reduction in operator dermal exposure using the prototype with respect the spray lance. Normalising the deposits at the common volume rate of 1000 L/ha, the operator body collected 1653 mL/h with the spray lance, mainly located on the chest and on the right side, and only 11 mL/h with the prototype. These results should promote the prototype development, assessing its performance, work capacity, quality of spray deposition on the plants, adaptability to different greenhouse structures.

Key words
Spray lances, Water-sensitive papers Optical analysis.

Introduction

Several studies (Cerruto *et al.*, 2007; Sánchez-Hermosilla *et al.*, 1998; Ergonen *et al.*, 2005) have pointed out that greenhouse crops are characterised by a large use of plant protection products (PPP). The most widespread sprayers for pesticide applications are simple handheld high pressure spray lances and spray guns, which subject operators to high risks of dermal and respiratory exposure. Moreover, the peculiar climatic conditions inside greenhouses (high temperatures, high relative humidities), make unpleasant to wear proper personal protective equipment (overall, gloves, boots, face mask, helmet), so the risk of exposure increases.

Some Authors (Cerruto *et al.*, 2008; Bjugstad and Torgrimsen, 1996; Tuomainen *et al.*, 2002) report high values of dermal exposure while spraying in greenhouses using hand-held spraying equipment. The exposure can be greatly reduced using manually moved trolley with vertical spray booms or self-propelled sprayers as the "Fumimatic" (Nuyttens *et al.*, 2005) or the "Fisher Turbomobil" (Planas de Martí *et al.*, 2001), suitably designed to operate in greenhouses. They are not yet commercially widespread, but their performances are quite

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promising.

A similar little tractor equipped with a spraying system is also at an advanced stage of development thanks to a close cooperation between the Mechanics Section of the Department of Agricultural Engineering (DIA) of the University of Catania and the manufacturer. The tractor comes from a tracked platform moved by an electric motor and developed for service purposes in greenhouse, which we hope to automatize thanks to a cooperation with the Dipartimento di Ingegneria Elettrica Elettronica e dei Sistemi (DIEES) of the University of Catania.

In this paper we discuss the results of some trials aimed at evaluating the operator dermal exposure during a simulation of a treatment of full developed tomato plants, comparing this prototype of sprayer and a standard spray lance.

Materials and methods

Plant and greenhouse features

The experimental trials were carried out in a tomato greenhouse located in the province of Ragusa (Sicily). The plants, cv *Tyty*, full developed, Y-shaped, were arranged in twin rows, with distance between rows of 0.56 m, distance between twin rows of 1.40 m, and row spacing of 0.70 m. The plant density was therefore about 14600 ha^{-1}.

The plants were geometrically characterised measuring minimum and maximum height of the foliage to be sprayed, and the thickness at two heights. Measurements were carried out on 16 plants of 8 twin rows.

The greenhouse had a metallic structure, covered with plastic film. The minimum height was 2.70 m, the maximum 4.50 m. It had 15 spans, each 29 m long and 8 m wide, so the total surface was some 3600 m^2. A lateral aisle 1.10 m wide provided for internal movements of operators during crop activities.

Spraying equipment

Spraying tests were carried out with the prototype of sprayer (Figure 1) and with a spray lance (Figure 2), used as reference.

Figure 1. Prototype of sprayer.

Figure 2. Handheld spray lance.

The prototype consists of a little tracked tractor powered by an air cooled, 4-cycle, single cylinder, gasoline engine. Continuous and maximum power are 2.6 and 4.2 kW at 3000 and 4000 rpm, respectively. The tractor carries a 120 L main tank, a volumetric pump, and two vertical spray booms 1.5 m long, each with four nozzles, 0.5 m spaced. The main dimensions, including the tank, are: length = 1650 mm, height = 1100 mm, and width = 730 mm. Driver seat and spray booms are suitably apart, so to keep the driver away from the spray jet and then to reduce his exposure. Spray booms height and reciprocal distance, as well as nozzles direction, can be suitably adjusted according to the crop needs.

Experimental tests were carried out using turbulence Albuz ATR yellow nozzles (orifice dimeter = 1.2 mm) at the pressure of 1.5 MPa. The flow rate was calculated connecting each nozzle to graduated cylinders by means of flexible pipes and measuring the delivering time.

The spray lance, 0.97 m long, had 4 steel nozzles, 0.21 m spaced. This long model was chosen to better reach the high parts of the plants canopy (Figure 3). The flow rate was measured at the pressure of 1.5 MPa. A pressure gauge installed near the helve allowed for checking the effective pressure value during spraying (Figure 2).

Experimental plan

The experimental trials with the spray lance consisted in a path (outward and return, 56.6 m long) between two twin rows, replicated three times (Figure 4). The operator walked forward, as in an ordinary pesticide application. Measuring the spraying time and knowing row length and flow rate at the nozzles, walking speed and volume application rates were also calculated (Table 1).

The experimental tests with the prototype consisted in spraying six twin rows, as depicted in Figure 5. Given the different flow rate at the nozzles and forward speed, the volume rate was 1070 L/ha (Table 1).

Figure 3. Spraying tests with the spray lance.

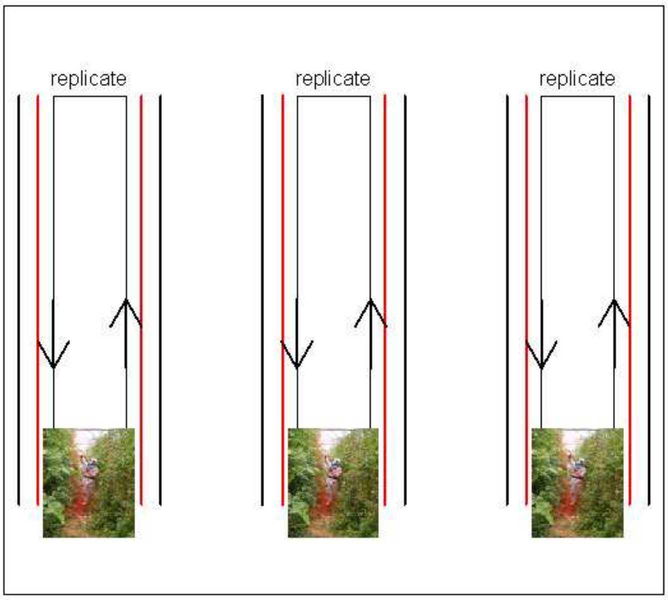

Figure 4. Experimental layout of the spraying test with the spray lance.

Spraying tests were carried out delivering a water solution with 2% of food dye Red Poinceau used as a tracer, to which a surfactant was added. During the spray, the operator was wearing protective personal equipment (PPE) consisting in a polypropylene disposable overall, completed with cover shoes, air forced full-face helmet, and latex gloves (Figure 6). Five water-sensitive papers were applied to the helmet (front, back, left, right, and top) to evaluate the head exposure.

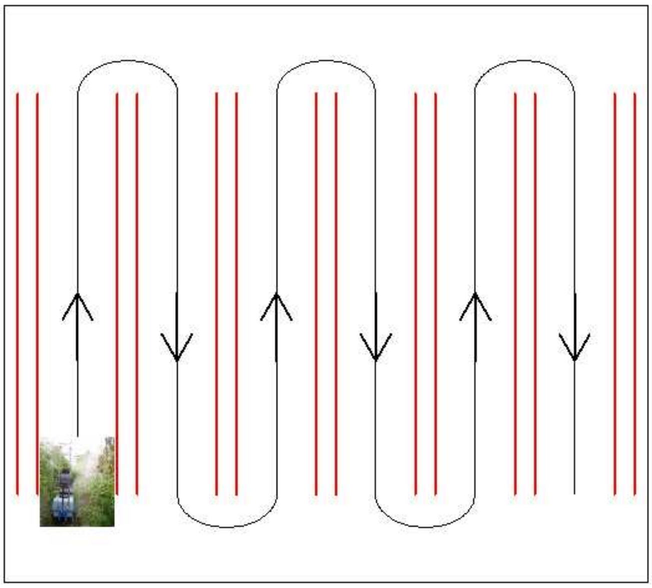

Figure 5. Experimental layout of the spraying test with the prototype of sprayer.

Figure 6. PPEs during spraying.

Table 1. Experimental plan.

Sprayer	Pressure, MPa	Flow rate, L/s	Speed, m/s	Volume rate, L/ha
Prototype	1.5	0.15	0.74	1070
Lance	1.5	0.06	0.85	700

After spraying, the overall was cut in several pieces (chest, back, legs, arms, hands, and feet) and the contamination of each piece was measured in laboratory by means of a spectrophotometer (Jenway model, Jenway Ltd), according to the following procedure:

1. Wash each overall piece with a known quantity V_c (mL) of distilled water in order to extract the dye;
2. Measure the absorbance A_c of about 5 mL of the solution by means of the spectrophotometer. The wavelength (511 nm) to which carry out the readings was previously experimentally determined as that corresponding to the maximum absorption;
3. Measure the absorbance A_m of the mixture delivered in field;
4. Calculate the volume of mixture deposited on each overall piece as:

$$v_c = \frac{A_c}{A_m} V_c$$

5. Calculate the unitary contamination as:

$$d_c = \frac{v_c}{S_c}$$

where S_c is the surface of each overall piece. To compensate for the differences in the volume rates, all values were normalised to the common volume rate V_N=1000 L/ha according to the equation:

$$d_n = \frac{V_N}{V_d} d_c$$

where V_d is the actual volume rate.

The water-sensitive papers were studied acquiring their image by means of a scanner with a resolution of 800 dpi and then analysing the images by means of a suitable software (the open source ImageJ 1.38x). For each image, surface coverage, number of particles per square centimetre (impact density), and particle size were evaluated. To account for the different sprayed area, surface coverage and impact density were expressed per twin row.

All computations, statistical analysis, and graphical representations were performed by means of the open source software R.

Results and discussion

Plant features

Table 2 reports the main geometrical characteristics of the plants canopy to be sprayed. The greatest variability was observed in thickness at 1.90 m and in minimum height of the foliage, whereas the maximum height was quite constant. Moreover, given the maximum height of about 2.80 m, to use a long spray lance model was preferred (Figure 3).

Table 2. Main geometrical features of the plants canopy.(1)

	Minimum height	Maximum height	Thickness at 1.40 m	Thickness at 1.90 m
Mean, m	0.68	2.81	0.41	0.36
Standard deviation, m	0.21	0.18	0.08	0.12
CV, %	31	6	20	34

(1) Average of 16 measures.

Operator exposure

The whole operator exposure was some 1653 mL/h of mixture with the spray lance and only 11 mL/h with the prototype. The great contamination measured with the spray lance provides evidence for the risks taken by the operator during pesticide applications in greenhouses, if not properly protected. This value (1653 mL/h) was much higher than that (223 mL/h) reported in Cerruto *et al.* (2008) because of the differences in plants and spray lance characteristics.

The ratio 1653:11 (~150:1) is comparable with the value 200:1 reported by Nuyttens using the Fumimatic, confirming as self-propelled sprayers can greatly reduce operator exposure compared to spray lances and improve safety and work productivity. Moreover, the value of 11 mL/h was lower than 26 and 40 mL/h measured with the spray lance when the operator walked backwards (Cerruto *et al*., 2008). So, this prototype of sprayer seems to ensure an exposure always lower than that given by spray lances.

When using spray lances walking forward, the operator chest resulted more exposed than the back (258 vs. 55 mL/h, Figure 7): this because the operator, moving forward, partly hit the sprayed cloud with his one's body. In addition, the operator right side resulted more exposed than the left side (55% vs. 26%), confirming the results reported in Cerruto *et al*., 2008. This because, being the exposure mainly due to the contact with the sprayed plants, when the operator walked forward between two twin rows, he scraped its right side against a sprayed row during both outwards and return path, whilst its left side only during the return path. As a consequence, right arm and right leg were the body parts more exposed, accounting for 21% and 16% of the total contamination respectively.

With the prototype (Figure 8), a little contamination was observed on the right hand (2.5 mL/h, 23% of the total dermal exposure), due to a running repair of the machine, and on the back (2.3 mL/h, 21%), the body part nearest to the nozzles.

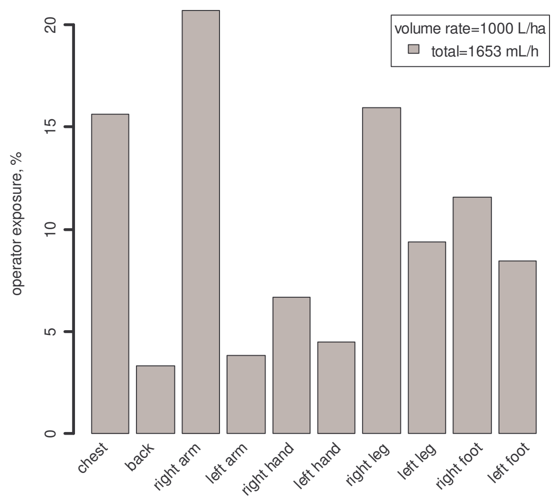

Figure 7. Percentage subdivision among the body parts with the spray lance.

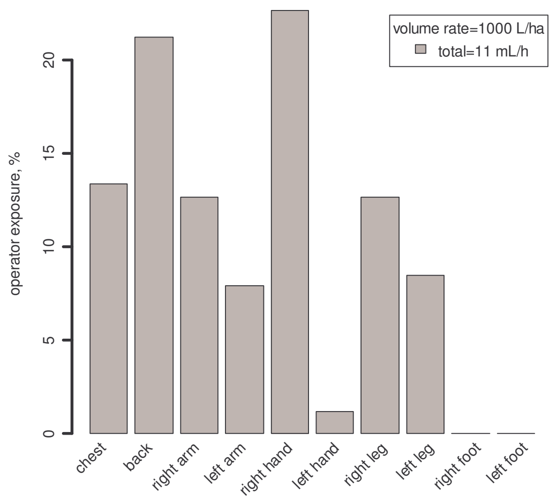

Figure 8. Percentage subdivision among the body parts with the prototype.

Using the spray lance, the weighted mean unitary exposure was 0.907 $\mu L/cm^2$ (Figure 9); the greatest value was on the right hand, which held the spray lance (3.955 $\mu L/cm^2$), followed by the right foot (3.315 $\mu L/cm^2$), which intercepted also part of the ground losses near the sprayed rows. The great specific exposure of upper (hands) and lower limbs (feet) should convince workers to always wear proper PPEs (gloves and boots) during spray applications.

With the prototype (Figure 10), the unitary exposure was much lower (weighted mean = 0.004 $\mu L/cm^2$), mainly concentrated on the right hand (0.052 $\mu L/cm^2$). Even if these values are negligible with respect the spray lance, nevertheless the operator should always wear proper PPEs, as unforeseen events could be noxious.

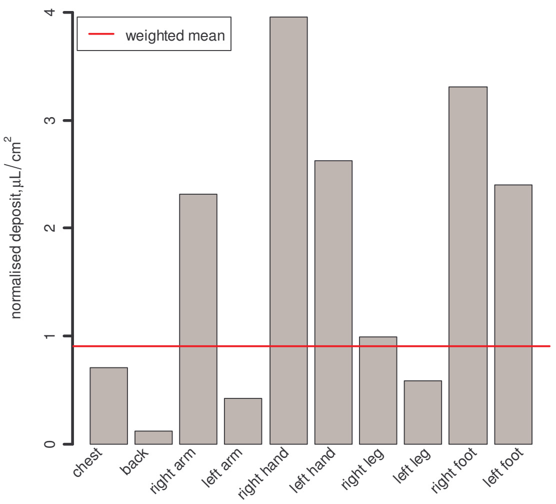

Figure 9. Unitary deposits with spray lance.

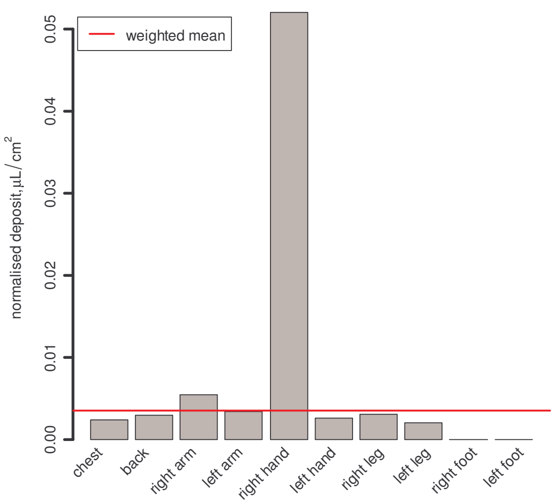

Figure 10. Unitary deposits with prototype.

Water-sensitive papers analysis

The water-sensitive papers produced results in agreement with the deposition measurements. In fact, the average covered surface was 22.9% for the spray lance and only 0.10% for the prototype (Figure 11). With the spray lance, the greatest coverage was recorded on the front (56.60%) and on the top (44.73%) of the helmet. Similarly, the average impact density was 148 cm^{-2} for the spray lance and 4 cm^{-2} for the prototype (Figure 11). The greatest values using the spray lance were again recorded on the top (309 cm^{-2}) and on the front (293 cm^{-2}) of the helmet.

These results reaffirm the great reduction in exposure working with the prototype, as well as the need to always properly protect the head.

Finally, Figure 12 reports the particle size distribution recorded by the water-sensitive papers, expressed as equivalent diameter, i.e. the diameter of the circle with the same area. Using the spray lance, the mean particle equivalent diameter was 299 µm, while using the prototype was 169 µm. The range was quite different: 36-732 µm for the prototype and 36-1551 µm for the spray lance.

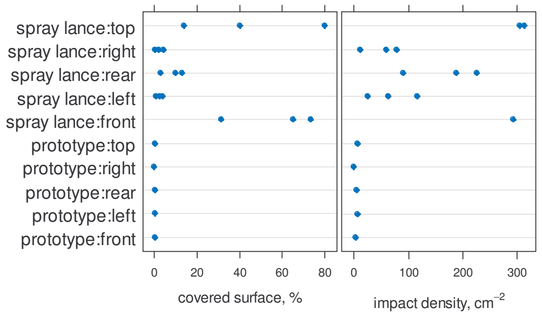

Figure 11. Percentage of covered surface and impact density.

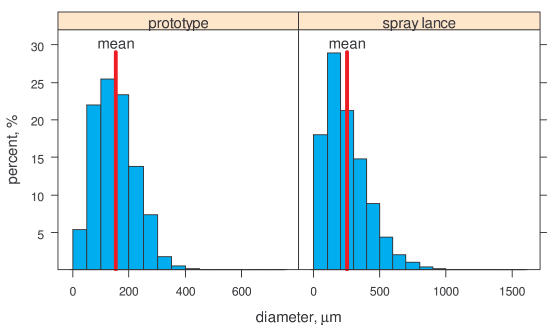

Figure 12. Equivalent diameter distribution.

Conclusions

Handheld high pressure spray lances are the most common equipment for spray application to greenhouse crops (Cerruto *et al*., 2007). Given the usually high volume rates and the high frequency of application, operators are at high risk of dermal and respiratory exposure if not properly protected with adequate personal protective equipment.

In this research we measured the operator dermal exposure while spraying full developed tomato plants, comparing a conventional handheld spray lance and a prototype of self-propelled sprayer suitably designed to properly work in greenhouses. The results showed a dramatic reduction in operator exposure using the prototype: with a reference volume rate of 1000 L/ha, the operator body collected 1653 mL/h with the spray lance and only 11 mL/h with the prototype. If considered necessary, further reductions can be achieved installing a transparent screen rear the seat driver, so limiting that drifting droplets can reach the back of the operator. The experimental trials gave also some suggestion about the air forced, full-face helmet, which seems well endured by the operator when he was walking or driving the tractor, even if more focused researches are necessary.

These results demonstrate that operator safety during pesticide application to greenhouse crops can be greatly improved. Nevertheless, the operator should always wear proper PPEs against dermal and respiratory exposure. Moreover, these results should encourage further studies on the prototype development, assessing its performance, the quality of deposition on the plants, and improving its adaptability to different greenhouse structures.

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