# Evaluation of dermal exposure to pesticides in greenhouse workers

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## Abstract
**According to a survey carried out at the Department of Agricultural Engineering of the Catania University, farmers in the province of Ragusa realise greenhouse plant protection by means of 15-20 spray applications, delivering volume rates ranging from 900 up to 1800 L/ha, according to the plants growth. The most widespread machineries are handheld high pressure spray lances, which expose the operators to high risks of dermal contamination.**
**This paper reports the results of some trials aimed at measuring the dermal exposure of operators during spray applications to tomato plants full developed. Experimental tests were carried out comparing two handheld spray lances, two working pressures (1 and 2 MPa), and two walking directions (forward and backwards). The spray lances were a "Yamaho C-6" lance with two nozzles, each with two orifices, and a high pressure spray lance with one 1.5 mm diameter turbulence nozzle.**
**The results showed as the dermal operator exposure could be greatly reduced performing spray applications walking backwards: with a reference volume rate of 1000 L/ha, the operator contamination was in fact 223 mL/h walking forward and 26 mL/h walking backwards. Moreover, when he walked forward, the greatest unitary depositions were on the right hand (0.550 µL/cm$^2$), the right foot (0.389 µL/cm$^2$), and the right arm (0.352 µL/cm$^2$), while when he walked backwards, they were on the feet (right = 0.080 µL/cm$^2$ and left = 0.075 µL/cm$^2$).**
**Fixing the operator movement (backwards), pressure and type of sprayer didn't affect exposure: it was on average 40 mL/h, m**ainly located on upper limbs (51.5%).

**Keywords:** spray lances, pressure, tomato.

## Introduction

According to the Italian Central Statistics Institute (ISTAT, 2006), horticultural protected crops in Sicily account for some 8800 ha and 430660 t, mainly located in the province of Ragusa (4750 ha and 272650 t). Greenhouses, however, given the peculiar structural and climatic conditions (confined space, high temperature and relative humidity), are very specific agro-ecosystems with respect the open field. To ensure high productions, massive energetic and chemical (fertilizers and pesticides) inputs are necessary.

The risks in using pesticides are related to two main factors: intrinsic toxicity and level of exposure and absorption by organisms through the several apertures (dermal, inhalant, and ingestive). This is true not only for workers directly exposed, but also for consumers and common people, even if the absorption apertures can be quite different.

The risk of exposure for workers is present not only during pesticide applications, but also during mixture preparation, post-treatment operations, and activities connected to re-entry in greenhouses, such as harvesting (Aprea *et al*., 2002). A recent survey carried out in Italy (Cerruto *et al*., 2007) on about 200 horticultural and ornamental farms, revealed that each crop requires an average of 15 treatments, that the most common machineries are lances

*Research developed within the PRIN 2005 project: Machinery and their adjustment for a sustainable pest control in glasshouses.*

and spray guns (71%), and that the use of personal protective equipment (PPE) isn't widespread, especially in preparing mixtures, when concentrated products are to be manipulated. Similar results emerged from surveys carried out in Turkey (Ergonen *et al*., 2005) and Spain (Sànchez-Hermosilla *et al*., 1998): handling of chemical products is done without taking all precautions to prevent exposures (inadequate use of PPEs) and there is a marked unawareness about their danger and toxicity.

The risks of exposure increase when pesticide applications are made by means of handheld equipments, as increase the possibilities of a direct contact with the mixture (Bjugstad and Torgrimsen, 1996). Restricting studies to dermal exposure, the amount of mixture collected by the operator body is related to several factors: crop, spraying equipment, operator movement, environmental conditions. Some of them are investigated in this paper, which reports some of the results of a research developed within the 2005 National Relevant Interest Project (PRIN) "Machinery and their adjustment for a sustainable pest control in glasshouses". Namely, it reports the results of some operator exposure trials, measuring his contamination during spray applications to tomato plants full developed by means of handheld high pressure spray lances, comparing operator movement, type of spray lance, and working pressure.

## Materials and methods

*Planning of the experimental tests*

The paper reports the results of a research activity developed in two steps. Firstly, the operator exposure was measured, comparing forward and backwards movement and using a handheld spray lance at fixed pressure (Trial 1). Secondly, on the basis of the results obtained, the experiment was repeated, varying pressure and type of spray lance (Trial 2).

In both experiments, spray applications were performed on tomato plants fully developed.

*Plants features*

Experimental trials were carried out in two greenhouses located in the territory of Ragusa, area where greenhouse crops are very widespread. The plant protection is usually accomplished by means of 15-20 spray applications per year, delivering, mainly by means of high pressure handheld spray lances, volume rates ranging between 900 up to 1800 L/ha, according to the plants development.

The crop, cv *Ikram*, was arranged in twin rows, with the main characteristics reported in Table 1. As a significant part of the operator contamination is due to its contact against the sprayed plants, their main geometrical features were measured (Table 2).

**Table 1. Main crops features.**

| Trial | Distance between rows, m | Distance between twin rows, m | Row spacing, m | Plant density, $ha^{-1}$ |
|---|---|---|---|---|
| 1 | 0.55 | 1.25 | 0.35 | 31 700 |
| 2 | 0.60 | 1.40 | 0.35 | 28 600 |

**Table 2. Main geometrical features of the sprayed area on the plants.(1)**

| Trial 1 | | | | | | |
|---|---|---|---|---|---|---|
| | Minimum height | Maximum height | Thickness at 0.60 m | Thickness at 1.00 m | Thickness at 1.40 m | Thickness at 1.80 m |
| Mean, m | 0.49 | 1.98 | 0.46 | 0.48 | 0.45 | 0.36 |
| CV, % | 27 | 3 | 27 | 15 | 19 | 34 |
| Trial 2 | | | | | | |
| | Minimum height | Maximum height | Thickness at 0.95 m | Thickness at 1.50 m | Thickness at 1.95 m | |
| Mean, m | 0.83 | 2.45 | 0.45 | 0.58 | 0.63 | |
| CV, % | 26 | 8 | 33 | 30 | 28 | |

(1) Average of 12 measures.

*Experimental tests*

The first experimental trial was carried out using the most widespread equipment, that is a handheld spray lance "Yamaho C-6" with two steel nozzles, each with two orifices (Figure 1). The selected working pressure was 2 MPa, that usually adopted by farmers. The flow rate at the nozzles was that reported in Table 3. Spray applications were performed walking forward (the commonest manner) and backwards. For each modality, three replicates were made, each consisting in a 60 m path (outward and return) between two twin rows. Measuring the walking speed and knowing the flow rate at the nozzles, the volume application rates were also calculated (Table 3).

Given the results of the first trial, the experiment was repeated in a similar manner, fixing the operator movement (backwards) and comparing two pressures (1 and 2 MPa) and two spray lances (the Yamaho-C6 and a "conventional" one with one turbulence nozzle, 1.5 mm diameter, Figure 2). The effective pressure values were checked by means a pressure gauge installed near the helve.

A full factorial experiment was designed, with two pressures, two spray lances, and three replicates, arranged according to a randomised complete block design (Table 3). The greater walking speed (0.8 m/s vs. 0.5) was due to the different features of the plants (lower size of the vegetation to be sprayed).

**Table 3. Experimental plan.**

| Trial 1 | | | | | |
|---|---|---|---|---|---|
| Movement | Spray lance | Pressure, MPa | Speed, m/s | Flow rate, L/s | Volume rate, L/ha |
| forward | Yamaho-C6 | 2 | 0.6 | 0.08 | 1423 |
| backwards | Yamaho-C6 | 2 | 0.5 | 0.08 | 1649 |
| Trial 2 | | | | | |
| backwards | Yamaho-C6 | 1 | 0.8 | 0.06 | 698 |
| backwards | Yamaho-C6 | 2 | 0.8 | 0.08 | 1010 |
| backwards | Conventional | 1 | 0.8 | 0.07 | 801 |
| backwards | Conventional | 2 | 0.8 | 0.09 | 1127 |

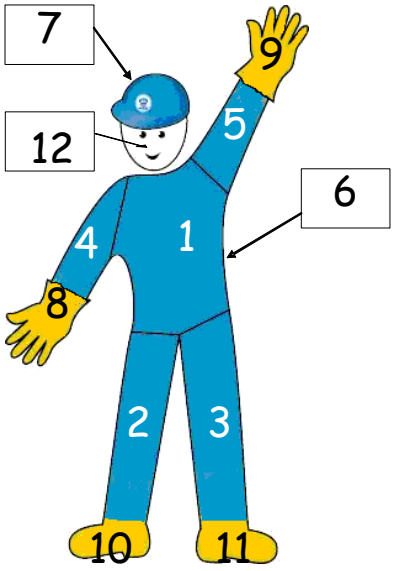
**Figure 1. Handheld Yamaho-C6 spray lance.**

**Figure 2. Conventional spray lance.**

Spray applications were performed delivering a water solution with 2% of food dye Red Poinceau used as a tracer. The operator was wearing a polypropylene disposable overall, completed with cover shoes, respirator, and latex gloves (Figure 3). After each replicate, the overall was cut in several pieces as depicted in Figure 4, and the contamination of each piece was measured in laboratory by means of a spectrophotometric technique. It was expressed in microlitres per square centimetre and in millilitres per working hour. To account for the differences in the spray volume rates, values were normalised to the common volume rate of 1000 L/ha.

Data was statistically analysed, separately for each trial. All computations and graphical representations were performed by means of the open source software R.

**Figure 3. Overall to measure the operator exposure.**




1: chest
2: right leg
3: left leg
4: right arm
5: left arm
6: back
7: head
8: right hand
9: left hand
10: right foot
11: left foot
12: respirator

**Figure 4. Scheme to measure the operator exposure.**

## Results

The Trial 1 results showed that, delivering 1000 L/ha, the operator contamination was 223 mL/h walking forward and 26 mL/h walking backwards. The ratio was 8.6:1, but for some body parties (chest, left arm, left hand, left leg), it was greater than 10:1. The greater contamination walking forward is mainly due to the operator contact with the sprayed plants, but also to the fact that he partly hit the sprayed cloud with his one's body.

Looking at the data more in depth (Figure 5), one can observe that, walking forward, the operator right side (arm, leg, hand, and foot) was ever more exposed than the left one, while the opposite happened walking backwards. This because the operator scraped his body against the sprayed plants: when he walked forward, he scraped its right side against a sprayed row during both outwards and return path, and its left side against a sprayed row only during the return path. When he walked backwards, he scraped only its left side against a sprayed row only during the return path. In both cases, legs were the body parts that accounted for the greatest contamination (Figure 6): 40% walking forward and 48% walking backwards. This because the foliage to be sprayed was starting from almost the ground (Table 2), so the operator, oscillating the spray lance, inevitably was directing the spray jet against his lower limbs.


**Figure 5. Trial 1: operator exposure per working hour.**

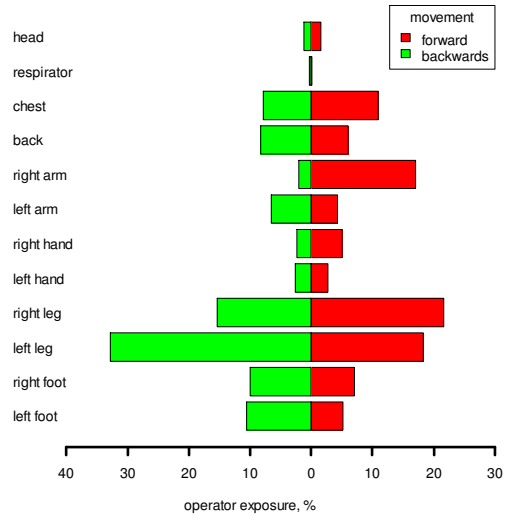



**Figure 6. Trial 1: percentage exposure subdivision among the body parts.**

Walking forward, the greatest unitary deposition (Table 4) was on the right hand (0.550 μL/cm$^2$), followed by the right foot (0.389 μL/cm$^2$), and by the right arm (0.352 μL/cm$^2$), while walking backwards, the greatest values were on feet (0.080 and 0.075 μL/cm$^2$, left and right respectively).

As these results demonstrated that the operator exposure during spray applications could be greatly reduced walking backwards, subsequent Trial 2 experimental tests were designed accordingly.

The analysis of variance showed as neither pressure nor type of spray lance influenced significantly the overall contamination of the operator (Figure 7). On average, delivering 1000 L/ha, the operator collected on his body 40 mL/h of mixture. This value is comparable with

26 mL/h, measured in similar conditions in the previous experiment. The reduction in the exposure measured with the Yamaho-C6 spray lance at the pressure of 2 MPa (14 mL/h) was not statistically significant.

**Table 4. Trial 1: unitary deposition (µL/cm$^2$) on the body parts.**

| body part | forward | backwards | ratio | body part | forward | backwards | ratio |
|---|---|---|---|---|---|---|---|
| head | 0.053 | 0.005 | 9.99 | right hand | 0.550 | 0.035 | 15.68 |
| respirator | 0.030 | 0.018 | 1.65 | left hand | 0.299 | 0.040 | 7.48 |
| chest | 0.094 | 0.009 | 10.16 | right leg | 0.252 | 0.025 | 10.26 |
| back | 0.053 | 0.010 | 5.33 | left leg | 0.214 | 0.054 | 3.94 |
| right arm | 0.352 | 0.006 | 59.02 | right foot | 0.389 | 0.075 | 5.17 |
| left harm | 0.091 | 0.019 | 4.68 | left foot | 0.281 | 0.080 | 3.53 |

Figure 8 shows the percentage subdivision of the mixture collected by the operator among his body parts. It shows the great exposure of the left arm, that alone accounted for 39% of the overall contamination. This result is in agreement with the spray applications carried out walking backwards. As a whole, hands and arms accounted for 51.5% of the total exposure, head and trunk for 24.1%, and legs and feet for 24.4%. The greater exposure of the upper limbs with respect the previous results, must be related to the different plants features (Table 2): as the foliage to be sprayed was starting from about 0.8 m, the operator was directing the spray jet preferably upwards.

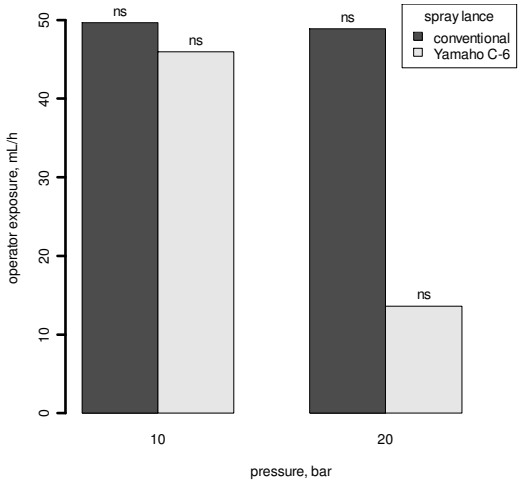



**Figure 7. Trial 2: operator exposure vs. pressure and spray lance type (ns: differences not statistically significant).**


**Figure 8. Trial 2: percentage exposure subdivision among the body parts.**

The weighted unitary deposition (Figure 9) ranged from 0.008 µL/cm$^2$ to 0.031 µL/cm$^2$,

with a mean value of 0.024 μL/cm$^2$. The most contaminated body part was the left arm (0.116 μL/cm$^2$, Figure 10) due to its scraping against the sprayed plants, followed by the right hand (0.082 μL/cm$^2$), that was holding the spray lances.

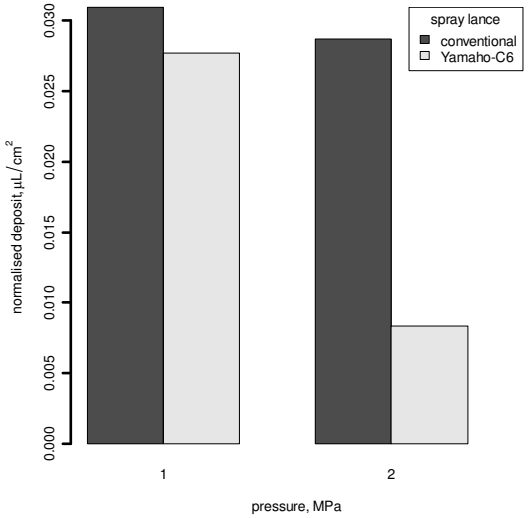



**Figure 9. Trial 2: normalised deposit on the operator vs. pressure and type of spray lance.**

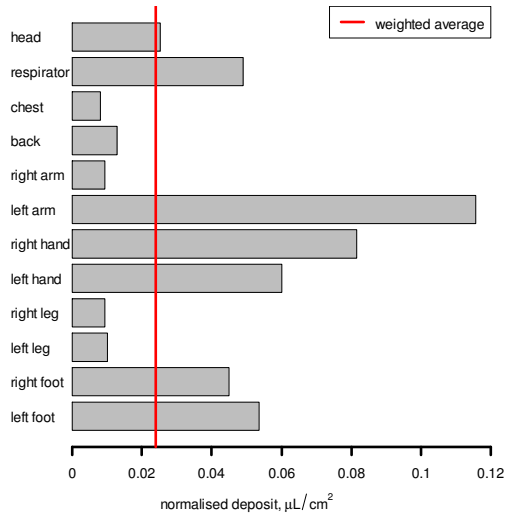



**Figure 10. Trial 2: average normalised deposit on the body parties of the operator.**

## Conclusions

Greenhouse crops usually require a high number of spray applications, with volume rates often greater than 1000 L/ha. The most widespread spray machineries are handheld high pressure spray lances, which expose operators to high risks of contamination. Furthermore, operators show little regard for safety aspects, not properly wearing adequate personal protective equipment.

So in this piece of research the measurement of the volume of mixture collected by the operator body during the treatment of full developed tomato plants was investigated. Comparing two pressures (1 and 2 MPa), two types of spray lance (with one and two nozzles), and two types of operator movement (forward and backwards), the results showed as the main factor in reducing the exposure is the operator movement: with a reference volume rate of 1000 L/ha, the operators collected on his body 223 mL/h of mixture walking forward and 26 mL/h walking backwards. As the working capacity is only little reduced (Table 3), carry out spray applications walking backwards should be preferred for safety reasons.

The body parts more exposed were related to the plants features: when the foliage to be sprayed started from almost the ground, the highest contamination was found on the lower limbs, while when the foliage started from about 0.8 m, the highest contamination was found on the upper limbs. These results should convince operators of wear proper PPEs in any circumstance, so to safeguard their own safety.

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