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Performance of Different Work Clothing Types for Reducing Skin Exposure to Pesticides During Open Field Treatment

Carmela Protano · Maurizio Guidotti · Matteo Vitali

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Abstract The aim of this study was to estimate the performance of different work clothing types for reducing skin exposure to five pesticides (azinphos-methyl, terbutylazine, alachlor, dimethoate, and dicamba) in field distribution by tractor equipped with boom sprayer. Performance was assessed by measuring the penetration factors of different types of work clothing. The results show that the protection offered by personal protective equipment (PPE) was always >97%, whereas the performance of cotton garments ranged from 84.1% to 92.5%. The different cotton garments differed significantly in their permeability, and the upper part of the body was the anatomical region showing the greatest values of the penetration factors. These results confirm the necessity of using PPE properly to minimise dermal exposure to pesticides.

Keywords Clothing penetration factor · Dermal exposure · Pesticide · Agricultural worker

Occupational exposure to pesticides is a major risk of agricultural activities because of the potential adverse effects on workers' health. In fact, a large amount of research confirms that the use of pesticides is associated with several acute and chronic diseases, such as rashes, skin, eye, and respiratory illnesses, as well as the development of some cancers (Blair et al. 2005).

There are three major pathways by which these chemicals enter the body: inhalation, oral uptake, and dermal absorption. It is well established that skin absorption is the most common route of exposure for pesticides under typical working conditions in an agricultural field (Garrod et al. 1998; Machera et al. 2003); consequently, protection afforded by garments or Personal Protective Equipment (PPE) must be considered essential for minimising the dermal exposure of pesticide handlers.

The general aim of this study was to estimate the performance of different work clothing types in reducing pesticide exposure during complete pesticide treatment – involving the mixing, loading, and application of the chemical – in an actual field scenario. For this purpose, the study measured the penetration factor (PF) of the clothing worn by operators. PF can be defined as the fraction of pesticide that crosses the clothing barrier and is available to contact the skin (Driver et al. 2007). It is calculated using dermal exposure monitoring data collected from a group of field pesticide handlers.

The specific objective in the study was to assess clothing PF for each part of the body and estimate variation in dermal exposure for different anatomical regions of monitored workers.

C. Protano · M. Vitali (✉)
Dipartimento di Scienze di Sanità Pubblica "G. Sanarelli", Università di Roma "La Sapienza", Piazzale Aldo Moro 5, 00185 Rome, Italy
e-mail: matteo.vitali@uniroma1.it

M. Guidotti
A.R.P.A. Lazio, Sede di Rieti, Via Salaria per l'Aquila, 8, 02100 Rieti, Italy

Materials and Methods

Field dermal exposure data was collected during 10 complete pesticide treatments, which consisted of the mixing, loading, and application by tractor of pesticides in fields in central Italy. Selected operators were identified using numbers from 1 to 10. These operators carried out field distribution by tractors equipped with trailer-mounted spray tanks with booms at the rear.

The period of study was from May to June 2005, and the pesticides used were Azin PB 30 (azinphos-methyl), Lasso Micromix (terbutylazine and alachlor), Rogor (dimethoate), and Sivel 21S (dicamba). In cases when two different active ingredients were used in a single formulation (Lasso Micromix; operators 1, 6, 7, and 10), dermal exposure levels were evaluated for each of the ingredients.

Table 1 reports details of exposure conditions for all treatments monitored, including active ingredients, cultivation, work period, weather conditions, and PPE or cotton garments worn by monitored operators. In this study, the PPE used by the workers consisted of Tyvek coveralls, helmets, gloves, and rubber boots. During the work shift, operators wore prewashed cotton garments or new Tyvek coveralls and gloves in order to avoid skin and garment contamination due to carry-over from previous work days.

Dermal exposure data were obtained using the pads technique. Two sets of 10 × 10 cm pads of α-cellulose were used. The first set of "external" pads was attached to the PPE/garments of each operator at various locations on the body, as indicated in Table 2. The locations were those recommended in the OECD protocol (OECD 1997), adapted to the specific situation of this study: when any selected anatomical region was not covered by garments, only one pad was placed directly on the skin. The "internal" pads were located in the same positions as the external ones, but were not covered by them.

All pads were removed at the end of the work shift, and the amount of residue on each pad was determined using previously described analytical methods (Vitali et al. 2009).

Table 1 Details of exposure conditions for each pesticide treatment

Operator	Active ingredient(s)	Total active ingredient distributed (g)	Cultivation	Work period (min)	Air temperature[a] (°C)	Relative humidity[a] (%)	Wind speed[a] (Km/h)	PPE/garment[b]
1	Terbuthylazine	8,640	Maize	195	27	52	1.8	Short-sleeved cotton shirt
	Alachlor	20,160						Long trousers
								Rubber boots
2	Azinphos-methyl	300	Sugar beet	133	27	41	4.0	Complete PPE set
3	Dicamba	3,600	Maize	128	25	50	2.3	Long-sleeved cotton shirt
								Long trousers
								Rubber boots
4	Dimethoate	810	Sugar beet	87	28	52	2.1	Complete PPE set
5	Azinphos-methyl	200	Sugar beet	115	26	49	1.4	Complete PPE set
6	Terbuthylazine	5,760	Maize	147	29	51	2.4	Long-sleeved cotton shirt
	Alachlor	13,440						Long trousers
								Rubber boots
7	Terbuthylazine	10,080	Maize	220	26	54	1.8	Long-sleeved cotton shirt
	Alachlor	23,520						Long trousers
								Rubber boots
8	Azinphos-methyl	200	Sugar beet	124	27	46	2.3	Long-sleeved cotton shirt
								Short trousers
								Gym shoes
9	Dimethoate	1,620	Sugar beet	139	25	48	1.7	Complete PPE set
10	Terbuthylazine	7,200	Maize	186	28	51	1.2	Long-sleeved cotton shirt
	Alachlor	16,800						Long trousers
								Rubber boots

[a] Mean of single work shift

[b] Complete PPE set: Full face mask with type A2P3 filter, Tyvek suit with hood, gloves, rubber boots

Table 2 Potential and Actual Dermal Exposure (PDE and ADE, expressed in µg) for each part of the body of all operators

Operator		Head		Neck		Chest		Back		Upper arms		Forearms		Upper legs		Lower leg		Feet	
	Surface area (cm^2)	1,300		260		3,550		3,550		2,910		1,210		3,820		2,380		1,310	
	Location of pads	Head		Back of neck		Upper chest		Between the shoulders		Upper right arm		Left forearms		Right thigh		Left calf		Instep	
	Region of body represented	Head and face		Front and back of neck		Chest and stomach		Back		Upper arms		Forearms		Upper legs		Lower legs		Feet	
	Active ingredient(s)	PDE	ADE	PDE	ADE	PDE	ADE	PDE	ADE	PDE	ADE	PDE	ADE	PDE	ADE	PDE	ADE	PDE	ADE
1	Terbuthylazine	–	55.3	–	4.4	134.9	24.9	39.1	10.7	64.0	16.0	–	23.0	40.1	6.8	21.4	1.3	15.7	0.3
	Alachlor	–	83.6	–	3.6	223.7	39.1	60.4	14.2	104.8	26.2	–	39.9	62.3	9.3	29.3	2.6	39.3	2.0
2	Azinphos-methyl	2.3	0.0	0.2	0.0	4.3	0.0	2.1	0.0	2.6	0.0	2.5	0.0	2.7	0.0	0.0	0.0	1.2	0.0
3	Dicamba	–	9.7	–	0.9	24.1	9.9	16.3	6.0	9.3	3.8	3.8	1.3	9.6	3.2	4.3	0.9	3.0	0.5
4	Dimethoate	608.4	0.0	47.6	0.1	1576.2	46.2	1050.8	10.7	724.6	10.8	448.9	11.1	542.4	2.7	259.4	0.0	150.7	0.0
5	Azinphos-methyl	2.5	0.0	–	0.0	3.6	0.0	1.8	0.0	2.6	0.0	0.8	0.0	0.9	0.0	0.0	0.0	0.1	0.0
6	Terbuthylazine	–	5.1	–	0.3	9.6	1.8	2.8	0.4	2.9	0.6	1.6	0.5	2.1	0.2	1.7	0.0	0.5	0.0
	Alachlor	–	5.9	–	0.2	13.5	2.5	4.3	0.7	4.4	0.6	2.4	0.6	3.3	0.5	2.9	0.1	2.6	0.1
7	Terbuthylazine	–	14.3	–	0.6	29.1	6.4	10.7	2.8	15.1	3.5	6.1	1.6	8.4	1.5	3.6	0.4	4.3	0.1
	Alachlor	–	21.7	–	1.0	46.2	9.9	16.3	4.3	22.7	5.5	9.7	2.8	14.5	2.5	6.4	0.4	2.9	0.0
8	Azinphos-methyl	–	2.5	–	0.3	5.0	0.7	2.5	0.4	2.9	0.3	1.7	0.2	1.6	0.2	–	0.0	0.8	0.0
9	Dimethoate	852.8	0.0	64.5	0.1	2208.1	71.0	1136.0	35.5	87.3	2.6	43.6	2.2	326.6	9.8	142.8	2.1	117.9	0.2
10	Terbuthylazine	–	9.8	–	1.4	24.5	5.7	10.7	3.9	16.6	4.4	4.0	1.2	8.0	1.6	3.1	0.2	0.0	0.0
	Alachlor	–	21.3	–	1.7	37.6	7.5	16.0	6.4	24.7	6.4	5.8	1.0	11.1	1.7	4.8	0.2	0.0	0.0

Prior to the analysis of samples, were conducted several blank tests and recovery experiments on spiked pads. Data obtained showed values below limits of detection for all blank tests, and good recoveries, ranging from 93.2% to 100.7%. Detection limits for analytes were: azinphos-methyl 0.05 ng/cm^2, terbutylazine 0.05 ng/cm^2, alachlor 0.04 ng/cm^2, dimethoate 0.3 ng/cm^2 and dicamba 0.3 ng/cm^2.

External and internal pad residues were used to evaluate Potential Dermal Exposure (PDE) and Actual Dermal Exposure (ADE), respectively. PDE is defined as the total amount of pesticide in contact with the body surface of workers, including protective clothing, work clothing, and uncovered skin; ADE, in contrast, is the amount of pesticide in contact with uncovered skin, and therefore the fraction that passed through protective and work clothing and that poses a risk of being percutaneously absorbed (OECD 1997).

PDE and ADE were calculated by multiplying the residues of pesticide recovered from each pad by the corresponding surface areas (Table 2).

The resulting data were used to calculate the percentage of PF for each anatomical region as follows:

$$\text{PF anatomical region } (\%) = \frac{\text{ADE}}{\text{ADE} + \text{PDE}} \times 100$$

If any selected anatomic region was not covered by clothing, only one pad was placed directly on the skin and the residue found in the pad was used to calculate ADE. In these cases, PF values were not calculated.

Results and Discussion

Table 2 shows the results of PDE and ADE for each anatomical region of all monitored operators.

Table 3 presents the percentage of clothing PF for each part of the body of all operators and some descriptive statistical data about the protection offered by various types of PPE/garments.

PF values of operators that worked with a complete set of PPE (full face mask, Tyvek coverall, rubber boots, and gloves) ranged from 0.0% to 2.1%. Negligible values (operator 2 and 5) indicate complete body protection from pesticide dermal exposure; in these cases, PPE functioned as a complete barrier to pesticide penetration. Operators 4 and 9 also wore PPE, but the protection was not complete in these cases: mean values of PF were 0.9% and 2.1%, respectively. Penetration through the Tyvek coverall could be explained by improper utilization (incomplete closure of the coverall, rolling up of the sleeves) or penetration of pesticide through seams and zips (Aprea et al. 2004).

Operators 1, 3, 6–8, and 10 carried out their work wearing their usual work clothing: a long- or short-sleeved cotton shirt, long or short trousers, and rubber boots or gym shoes. Mean values of PF for these workers ranged from 7.5% to 24.0%.

Regarding cotton garments, pesticide characteristics seem to be insignificant in determining PF; operators 1, 6, 7 and 10 used a product based on two different active ingredients (Terbuthylazine and Alachlor) and relative PF was very similar: 16.0%–15.2% for operator 1, 13.1%–

Table 3 Penetration factor for each anatomical region and performance of garment data for all operators

No.	Active ingredient(s)	Penetration factor (%)									Mean
		Head	Neck	Chest	Back	Upper arms	Forearms	Upper legs	Lower leg	Feet	
1	Terbuthylazine	–	–	15.6	21.4	20.0	–	14.5	5.7	2.0	13.2
	Alachlor	–	–	14.9	19.0	20.0	–	13.0	8.3	4.8	13.3
2	Azinphos-methyl	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	Dicamba	–	–	29.2	27.0	28.9	26.2	25.4	16.7	14.5	24.0
4	Dimethoate	0.0	0.2	2.8	1.0	1.5	2.4	0.5	0.0	0.0	0.9
5	Azinphos-methyl	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	Terbuthylazine	–	–	15.6	11.1	16.7	23.5	8.3	2.9	0.0	11.2
	Alachlor	–	–	15.6	14.3	11.8	20.0	12.3	4.8	2.0	11.5
7	Terbuthylazine	–	–	18.0	21.1	18.8	20.6	15.3	9.1	2.0	15.0
	Alachlor	–	–	17.7	20.7	19.6	22.3	14.5	6.5	1.0	14.6
8	Azinphos-methyl	–	–	12.5	12.5	9.1	12.5	10.7	0.0	2.9	7.5
9	Dimethoate	0.0	0.1	3.1	3.0	2.9	4.8	2.9	1.5	0.2	2.1
10	Terbuthylazine	–	–	18.8	26.8	20.8	23.3	16.7	4.8	0.0	15.9
	Alachlor	–	–	16.5	28.6	20.6	14.3	13.0	4.8	0.0	14.0
	Mean	–	<0.1	12.9	14.8	13.6	14.2	10.5	4.7	2.1	11.9

13.9% for operator 6, 17.4%–17.7% for operator 7 and 20.2%–18.8% for operator 10.

PF values obtained for protective coveralls differ significantly from default data available from various statistical models designed to predict exposure to pesticides, such as the German Model (2.5%), UK POEM (14.5%), EUROPOEM (30%), and PHED (50%) (EUROPOEM I 1996; Tiramani et al. 2007). Except for the German Model, all models indicate PF values 10–30 times higher than in our study. However, these predictive models were developed at least 10 years ago, and progress in the design and manufacture of protective coveralls may have led to a large reduction in PF.

The PF values of the different cotton garments varied significantly for all operators, probably due to differences in pesticide handling methods and the characteristics of the work clothing. For these operators, the anatomical region that showed higher PF values was the upper part of the body (chest, back, and arms): the mean PF of the upper body was 18.7%, while the mean PF of the lower body was 8.1%. Similar data were obtained in other studies (Aprea et al. 2004; Machera et al. 2003). Upper body areas presumably showed higher PF levels due to differences between shirts and trousers. Typically, shirt fabrics are thinner than those of trousers. In addition, whereas trousers are closed at the extremities by boots, shirts have open ends at the neck and sleeves.

Our results highlight the necessity of using PPE to minimise dermal exposure to pesticides during agricultural activities. Furthermore, PPE can provide protection only when used appropriately.

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