Ann. Occup. Hyg., Vol. 52, No. 6, pp. 535–544, 2008

doi:10.1093/annhyg/men035

The Determinants of Dermal Exposure Ranking Method (DERM): A Pesticide Exposure Assessment Approach for Developing Countries

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Received 22 January 2008; in final form 13 April 2008; published online 7 July 2008

A new method for assessment of dermal exposure to pesticides in subsistence farmers by use of determinants of dermal exposure is described. The method, called the determinants of dermal exposure ranking method (DERM), is a combination of checklists and expert rating assessment. Thus, determinants are listed in a form, which is used to check their presence and to assess them using a simple algorithm based on two factors, the type of transport process (*T* value) and the area of body surface exposed (*A* value). In addition, the type of clothing worn during applications is included as a protection factor. We applied the DERM to real pesticide applications, characterizing dermal exposure and comparing DERM estimates with earlier developed semiquantitative visual scores based on fluorescent tracer, the total visual score (TVS) and contaminated body area (CBA). DERM showed a very good level of agreement with both the TVS ($r = 0.69$; $P = 0.000$) and the CBA ($r = 0.67$; $P = 0.000$). DERM allowed identification of the determinants that had the highest effect on exposure and the farmers with the highest exposure. In conclusion, DERM provided information on the determinants responsible for dermal exposure in a group of subsistence farmers. This can be useful to design monitoring and preventive programs, define priorities for intervention and prioritize and select most adequate measurement strategies. DERM promises to be a low-cost easy-to-use method to assess dermal exposure to pesticides in developing country conditions.

Keywords: determinants of dermal exposure; developing countries; exposure assessment; pesticides

INTRODUCTION

Several methods have been developed to assess exposure to pesticides and comprehensive reviews are available (Durham and Wolfe, 1962; Davis, 1980; Chester, 1993; van Hemmen and Brouwer, 1995). The use of these methods mainly depends on the presence of personnel well trained in analytical techniques and also expensive equipment. In developing countries, however, methods for assessment of exposure must be inexpensive and easy to use. Semiquantitative and qualitative methods such as Fenske's visual scoring system (VSS) (Fenske, 1988) and field observations are examples of such simple methods. Aragón *et al.* (2006) modified Fenske's VSS to identify patterns of dermal contamination and to estimate dermal exposure to pesticides in Nicaraguan farmers, and Blanco *et al.* (2005) identified the main determinants of dermal exposure to pesticides in Nicaraguan subsistence farmers through field observations.

Exposure to pesticides in farmers while using backpack sprayers mainly occurs through the dermal route (Machera *et al.*, 2003). According to these authors, dermal route represented >99.0% of the total exposure among farmers applying pesticides with

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backpack sprayers. Thus, while studying exposure to pesticides in farmers using backpack sprayers, we should aim to understand factors determining the level of exposure through dermal route. Dermal exposure can be described on the basis of the transport of contaminant mass from exposure sources to the surface of the skin (Schneider *et al.*, 1999). Thus, disentanglement of the transport processes involved in backpack spraying is required in order to assess the degree of exposure of these farmers by means of a careful judgment of their spraying activities.

Subsistence farmers in developing countries apply pesticides under high-risk conditions: they do not wear protective equipment, they repair spraying equipment in the field touching the contaminated nozzles with their bare hands and use leaky sprayers without avoiding contact with the pesticide solution (van Wendel de Joode *et al.*, 1996; Aragón *et al.*, 2001). In Nicaragua, subsistence farmers use backpack sprayers to apply pesticides on their crops, which are usually cultivated on 1–2 Manzana (1 Manzana = 0.7 Ha) of land. The use of any other application technique such as tractor-mounted boom sprayer is out of their economical possibilities. In a study of Nicaraguan subsistence farmers who applied pesticides with backpack sprayers, determinants of exposure related to work practices, spraying equipment and the worksite explained, respectively, 52, 33 and 25% of the dermal exposure variability (Blanco *et al.*, 2005). Under these conditions, Occupational Hygiene should shift from emphasis on exposure measurements to show compliance with regulations to emphasis on effective controls, i.e. it is less important to accurately quantify the exposure than it is to understand the determinants of exposure. Understanding of the relative importance of different exposure determinants is needed to orient control efforts toward those determinants that contribute most significantly to the exposure.

Validated methods for semiquantitative assessment of dermal exposure to pesticides applicable in developing country scenarios are practically nonexistent. A general method for semiquantitative assessment of dermal exposure, called the dermal exposure assessment method (DREAM), has been published (van Wendel de Joode *et al.*, 2003). This method consists of a multiple-choice questionnaire on exposure determinants and an evaluation algorithm. According to this algorithm, determinants are evaluated at the task level (or job level), assessing both the potential and the actual dermal exposures for nine different body parts, which permits estimation of the total dermal exposure in DREAM units. One limitation of this method may be that it does not include important determinants for exposure conditions in developing countries, although the list of determinants is large. In addition, the algorithm is tedious, so the data collection and analysis has to be carried out by experienced personnel as well as programmed in MS-ACCESS®.

In developing countries, pesticide exposure cannot always be assessed by hygiene experts; nor is it always possible to assess exposure quantitatively. Thus, we propose 'determinants of dermal exposure ranking method (DERM)', an easy-to-use method of exposure assessment based on determinants of dermal exposure, which could also be used to define priorities for prevention and training programs. We present here an example of how to use DERM in a group of Nicaraguan subsistence farmers, who applied pesticides with backpack sprayers.

METHODS

Transport process (T)

The determinants of dermal exposure ranking method (DERM) is a model in which specific determinants of dermal exposure are assessed on the basis of two factors: the type of transport process (T) and the area of the body surface (as a percentage) potentially affected by the determinant (A). In addition, clothing-related determinants (C) are evaluated as a protection factor.

The type of transport process is evaluated following the conceptual model for dermal exposure proposed by Schneider *et al.* (1999). According to this model, the contaminant can reach the skin through emission, deposition or transfer. Emission is the direct release from a source onto the skin or clothing (e.g. splashing, immersion of hands in the tank of the backpack sprayer, spilling while fixing nozzle or hose, etc.). Deposition is the settlement of the contaminant onto the skin or clothing from the air (e.g. walking into the spray cloud because of spraying against the wind). Transfer involves the transport from contaminated surfaces (e.g. contact with surfaces that got contaminated in previous applications or the present one, including transfer to clothes). Once the transport process is characterized, a score (1–5) is assigned.

To define the scores for transport processes, we assumed that transfer processes lead to low exposure, deposition processes lead to a medium exposure and emission processes lead to high exposure. A score of 1 was assigned to low exposure (transfer process), 3 or 4 to medium exposure (transfer from recently contaminated surfaces and deposition, respectively) and 5 to high exposure (emission processes). We identified two different situations in which transfer processes might happen: (i) from touching a surface that had been contaminated in previous applications or (ii) from touching a recently splashed/spilled surface or a plant that has recently been sprayed. However, we considered that (ii) leads to a medium exposure and a score of 3 was assigned to it (Table 1).

Table 1. Scores for categories of factors of transport and area of body surface used in DERM estimation

Factor	Category	Subcategory/example	Score
Transport (*T*)	Transfer	From a piece of clothing or by touching a previously contaminated surface	1
		Touching a recently splashed/spilled surface	3
	Deposition	Walking into the spray cloud, spraying against wind	4
	Emission	Introducing hand into the tank, fixing nozzle with bare hands	5
	Not applicable		1
Area of the body surface (*A*) (%)	0–20		1
	21–40		2
	41–60		3
	61–80		4
	81–100		5
	Not applicable		1

Area of body surface contaminated (A)

The area of the body surface expected to be contaminated by a particular determinant is ranked from 1 to 5, representing percentage ranges of the total body surface as follows: 0–20, 21–40, 41–60% and so on. The ranges and scores were defined arbitrarily, with the only assumption that within a category the level of exposure is approximately the same. To estimate the percentage of body surface, we used as guidelines the percentages proposed by Lund and Browder (1944) to estimate the proportion of body surface affected in burned patients (Fig. 1).

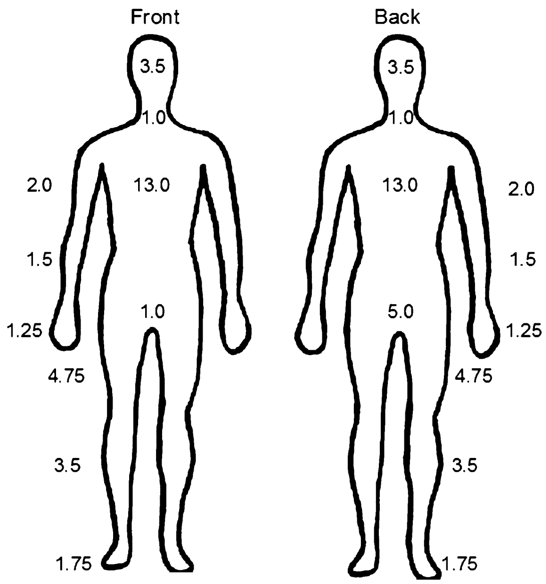


Fig. 1. Guideline to estimate the area (%) of the body surface potentially contaminated by each determinant; for upper and lower extremities, the figures represent only one side (right or left). The proportions were taken from the Lund and Browder (1944) chart to estimate the proportion of body surface affected in burned patients.

The clothing protection factor (C)

It is very common to see small-scale subsistence farmers spraying pesticides in normal clothing without any personal protective equipment. Since even normal clothing can provide some degree of protection (Stewart, 1999) and since different types of fabrics can reduce exposure to different extents, we considered it necessary to assess the different types of clothing worn by farmers and take this into account as a protection factor. Thus, the degree of protection provided by normal clothing can be described as a clothing protection factor (C) (Stewart *et al.*, 2001), which we defined as the complement of the reduction in the exposure level (1 − exposure reduction) that occurred due to the clothing worn. We assumed a maximum reduction in the intensity of exposure of 50% when the best clothing available was worn (long-sleeved shirt and long pants), thus giving a clothing protection factor of 0.5 ($C = 1 - 0.5$). On the contrary, a 0% protection was assumed for the worst clothing available (old/overused/torn shirt, old/overused/torn pants and being barefoot), thus yielding $C = 1$. Because of the different types of clothing that these farmers use to wear during pesticide applications, a proportional clothing protection factor was assigned to different pieces of clothing, so the total protection should be defined by adding the reduction in exposure provided by each piece of clothing (long/short-sleeved shirt and long/short pants). To define the corresponding proportion in exposure reduction for a piece of clothing (not old/overused/torn), we assumed that each piece of normal clothing reduced in 50% the intensity of exposure on that body surface it was covering and that this is equivalent to a 50% reduction in the covered area. Thus, the 50% of the area of the body surface (in percentage) that might be covered by each piece of clothing was used as the proportion (Table 2). In order to simplify the figures to be added while using the method in the field, we rounded them. Also, we

Table 2. Exposure reduction from each piece of clothing worn by Nicaraguan subsistence farmers during pesticide applications with backpacks (used to define a clothing protection factor, see text)

Piece of clothing	Covered body surface (%)	Exposure reduction
Shirt		
Long sleeved	42	0.20
Short sleeved	36	0.15
Old/overused/torn	0	0
Pants		
Long	39	0.20
Short	25	0.10
Old/overused/torn	0	0
Shoes		
Yes	7	0.10
No	0	0

assumed that shoes provided better protection than clothing (because of the material in shoes: leather or rubber) and used the total area of the feet as a protection factor (also rounded). For example, if we wanted to know the clothing protection factor for a farmer who wore a short-sleeved shirt and short pants, which were in good condition, but no shoes, we would add the assumed exposure reductions for short-sleeved shirt (0.15) and short pants (0.10); thus, $C = 1 - 0.25 = 0.75$.

The DERM assessment protocol

As explained above, DERM is a model in which specific determinants of dermal exposure are assessed on the basis of two factors: the type of transport process involved (T) and the area of the body surface potentially affected by the determinant (A), with the clothing (C) of the farmers as a protection factor. Factors T and A are combined by multiplication, where each combination represents a semiquantitative assessment of a specific determinant: $\text{Det}_i = T_i \times A_i$. The rationale for a multiplicative model is that the two factors are directly proportional to the exposure and act independently. Both factors are scored using ordinal numbers increasing proportional to the intensity of exposure. The area exposed does not depend on the type of transport or vice versa, hence each factor influences the determinant score independently of each other. Each determinant is evaluated independently and the scores of all determinants are summed. Finally, this sum is multiplied by the clothing protection factor (C) to estimate the DERM score.

In order to avoid a zero score for determinants, which cannot be evaluated in terms of transport and area of the body surface—such as 'sprayed crop area' and 'volume of solution sprayed'—these determinants are evaluated only as leading to low or high exposure. Nicaraguan subsistence farmers used to have crop areas of 1 'Manzana' (1 Manzana = 0.7 Ha) and spray about two (40 l) hand-pressurized or three (30 l) motor-pressurized backpack tank loads. Thus, we selected 0.7 Ha and 30 l as the cutting points to define low ($\leq$0.7 Ha and $\leq$30 l) or high levels of exposure for sprayed crop area and volume of sprayed solution, respectively. To define the scores for high/low levels of exposure, we used the data presented by Blanco *et al.* (2005) on the proportion of dermal exposure variability that can be explained by determinants related to worksite (0.25%) and work practices (0.52%). These proportions were multiplied by 10 and rounded to obtain natural numbers as follows—for worksite-related determinants: $0.25 \times 10 = 2.5$ and rounded to 2 and for work practice-related determinants: $0.52 \times 10 = 5.2$ and rounded to 5. The scores for low level were defined as half of that number (i.e. 1 for the worksite-related determinant and 2.5 for the work practice-related determinant).

Application of DERM

The study population. Details of the study population have been provided elsewhere (Aragón *et al.*, 2004; Blanco *et al.*, 2005). Briefly, subsistence farmers from the northwestern part of Nicaragua who planned to spray the organophosphate insecticides chlorpyrifos or methamidophos were considered eligible after participation at a meeting in which the purpose and the methods of the study were explained and a written consent form signed. A total of 32 applications performed by 30 farmers were included. The methods for development and validation of the DERM rating system are described below.

Determinants of dermal exposure. A list of 27 determinants of dermal exposure to pesticides in subsistence farmers and the methods for their identification were presented elsewhere (Blanco *et al.*, 2005). These determinants were classified into five groups: worksite, spraying equipment, clothing, work practices and hygiene practices related. In order to simplify the model, we excluded 11 determinants, the influence of which on dermal exposure was of complex nature in terms of transport processes and the area of body surface exposed. A multiple linear regression model constructed on the basis of the 16 determinants selected explained 73% ($r^2 = 0.73$; $P = 0.02$) of the total visual score (TVS), in contrast to 69% of the final model of Blanco *et al.* (2005), though in this case most of the coefficient of determination (β-coefficient) was not statistically significant. The determinants excluded were as follows: those related to weather (temperature and dew on plants) because they are independent of the farmer; those related to terrain conditions (slightly sloping terrain, wet or slightly muddy terrain) because their influence on dermal exposure is too complex (they increase the workload and thus sweating, which in turn wets clothing and increases its permeability); the type of pump (hand- versus motor-pressurized pump) because it defines some of the applicator's work practices, which are evaluated individually; the shirt worn partially unbuttoned (uncovering the chest or abdomen) because this depended on old/overused/torn condition of the conditions of the shirt, which is included in the clothing protective factor and those related to hygiene practices (rinsing hands during applications, wiping sweat off the face with a piece of cloth and sealing lid of the tank with a piece of cloth) because they were reactive rather than proactive (probably because we were observing). Finally, 'distance between the nozzle and the body of the farmer' and 'having a helper' were excluded because the former correlated with 'the height of the crop' and 'spraying in front' and the latter affected the determinants of exposure of the assistant and not the ones of the evaluated farmer. The list of included determinants is presented in Table 3. An example describing step by step the estimation of DERM for the farmer resulting in the worst case (the farmer with the highest DERM estimate) is presented in the Appendix, using the form developed to facilitate the application of DERM (Table A1).

TVS Fenske (1988) proposed a semiquantitative VSS to estimate pesticide exposure from visual observations of photographs, which was modified by Aragón *et al.* (2006) and used here for comparison. Aragón's modifications of the VSS were described elsewhere (Aragón *et al.*, 2006). In summary, a small amount of a fluorescent tracer was added to the pesticide solution to be sprayed by the farmers. The pattern of fluorescent images on the skin of the farmer after application was evaluated as follows. The body was divided into 31 parts and each part scored using a matrix with the abscissa representing the intensity of exposure and the ordinate representing the area of exposure. The intensity was scored from 0 to 5 (none to high). The area exposed was the proportion of the body part contaminated (ranked 0–5), adjusted according to the size of the body segment. The product of these two scores resulted in a value called body segment score (BSS). The sum of the exposed areas of each body segment represented the contaminated body area (CBA). The sum of all BSS represented the TVS. Theoretically, TVS may range from 0 to 453.

Table 3. List of determinants used to estimate dermal exposure to pesticides during applications with backpack sprayers among Nicaraguan subsistence farmers ($n = 32$) and their main values

	Determinant	Mean (range)	Yes/no
1	Sprayed surface (Ha)	1.25 (0.35–4.2)	
2	Height of the crop (cm)	57 (10–175)	
3	Leaking backpack		19/13
4	Volume of sprayed solution (l)	51 (10–120)	
5	Nozzle height (cm)	80 (40–160)	
6	Spraying with nozzle directed in front		12/20
7	Spraying against wind		20/12
8	Splashing/spilling spray solution over the pump		24/8
9	Splashes on the hands		23/9
10	Splashes on the feet		15/17
11	Gross contamination of the hands by blocking a hose leakage, repairing nozzle or entering hand into tank		15/17
12	Wearing long-sleeved shirt		15/17
13	Wearing an old/overused/torn shirt		19/13
14	Wearing long pants		24/8
15	Wearing old/overused/torn pants		5/27
16	Wearing shoes		5/27

Data analysis

We used the TVS and CBA estimates that were reported for the same pesticide applications to assess the performance of the model proposed. We compared DERM estimates to the TVS and CBA estimates by means of correlation coefficients and by visual contrast of the rankings of the estimates. Because DERM estimates were not normally distributed (Shapiro–Wilks test: $W = 0.868$; $P = 0.01$), we used the Spearman's correlation coefficient (ρ) instead of Pearson's correlation. To find out the reasons for differences in the rankings of the estimates, especially for those cases in which the contrast was large, we reviewed the videotapes of the application. All analyses were conducted using SPSS version 11 (SPSS Inc., Chicago, IL, USA).

RESULTS

The sum of the estimated scores for the determinants resulted in an average exposure estimate of 35.9 (SD = 11.1), with a range of 17.0–57.0, whereas the average DERM estimates, after applying the clothing protection factor, was 26.8 (SD = 11.3) with a range of 9.8–57.0 (Table 4). DERM allowed to identify those farmers with the highest level of exposure in the group and those determinants that most affected the exposure of those farmers. Thus, the applicators with the highest estimated exposure were those who participated in applications 4, 17, 2 and 1, with scores of 57.0, 57.0, 55.0 and 55.0, respectively. After applying the clothing protection factor, the ones with the highest DERM estimates were 4, 2 and 6 with scores of 57.0, 55.0 and 51.0, respectively.

On the other hand, the determinants that most affected the exposure in applications 4, 2 and 17 were

Table 4. Determinant estimates, clothing protection factors and DERM estimates for each pesticide application observed

Application	Worksite		Spraying equipment	Work practices								ΣDet	Clothing protection factor	Total
	1[a]	2	3	4	5	6	7	8	9	10	11			
1	2	9	10	5	12	0	4	3	5	0	5	**55.0**	0.60	33.0
2	2	9	10	5	12	0	4	3	5	0	5	**55.0**	**1.00**	**55.0**
3	2	3	5	2.5	4	0	0	3	0	5	5	29.5	0.60	17.7
4	2	6	0	5	8	10	8	3	5	5	5	**57.0**	**1.00**	**57.0**
5	2	3	10	5	4	5	8	3	0	0	0	40.0	0.60	24.0
6	2	3	10	5	4	5	4	3	5	5	5	51.0	**1.00**	**51.0**
7	1	6	0	5	4	0	8	3	5	0	5	37.0	0.60	22.2
8	2	3	5	5	4	0	0	3	5	0	0	27.0	0.65	17.6
9	2	3	0	5	4	0	4	3	0	5	5	31.0	0.90	27.9
10	2	3	0	5	4	5	4	3	0	0	5	31.0	0.70	21.7
11	2	3	0	5	4	0	4	3	5	5	0	31.0	0.75	23.3
12	2	3	5	2.5	4	0	4	3	0	0	0	23.5	0.90	21.2
13	2	6	5	2.5	8	0	0	3	5	0	5	36.5	0.65	23.7
14	2	3	5	2.5	8	0	8	0	5	0	5	38.5	0.50	19.3
15	2	3	5	2.5	4	0	4	0	5	5	0	30.5	0.80	24.4
16	1	3	0	5	4	5	4	0	5	0	0	27.0	1.00	27.0
17	2	6	10	5	8	0	8	3	5	5	5	**57.0**	0.70	39.9
18	1	3	10	5	4	5	4	3	0	5	0	40.0	0.70	28.0
19	2	3	10	5	4	5	0	0	0	0	0	29.0	0.60	17.4
20	1	6	5	2.5	8	0	0	3	0	0	0	25.5	**1.00**	25.5
21	2	3	10	5	4	5	4	0	5	5	5	48.0	0.80	38.4
22	2	3	10	5	4	5	0	0	5	5	0	39.0	0.60	23.4
23	2	3	5	2.5	4	0	0	0	5	5	5	31.5	0.80	25.2
24	2	3	5	5	8	0	8	3	5	0	5	44.0	0.80	35.2
25	1	3	0	2.5	4	0	4	0	5	0	0	*19.5*	*0.50*	*9.8*
26	1	3	0	2.5	4	0	4	3	5	0	0	22.5	0.80	18.0
27	2	3	10	5	4	5	0	3	5	5	5	47.0	0.60	28.2
28	2	9	0	5	12	0	0	3	5	0	0	36.0	*0.50*	18.0
29	2	6	0	5	8	0	8	3	5	0	0	37.0	0.90	33.3
30	1	3	0	2.5	4	0	4	3	5	5	0	27.5	0.70	19.3
31	1	3	0	2.5	4	0	4	3	5	5	0	27.5	0.65	17.9
32	2	3	0	5	4	0	0	3	0	0	0	*17.0*	0.80	*13.6*
Mean												35.9	0.74	26.8
Median	2	3	5	5	4	0	4	3	5	0	0	34	0.70	24.0
Minimum	1	3	0	2.5	4	0	0	0	0	0	0	17	0.50	9.8
Maximum	2	9	10	5	12	10	8	3	5	5	5	57	1.00	57.0

[a]See Table 3 for identities of each determinant.
The bold values represent the highest and the italicized the lowest values.

as follows: In the case of application 4 (the one with the highest DERM estimate) 'spraying with nozzle in front', 'nozzle height', 'spraying against the wind' and 'height of the crop' were the major determinants. In the case of application 2, the major determinants were 'nozzle height', using a 'leaking backpack', and the 'height of the crop'. In both cases, the clothing worn did not offer much protection. On the contrary, in application 17, the clothing helped to reduce exposure. For this application, using a leaking backpack, nozzle height and spraying against the wind were the most important determinants.

Average TVS and CBA estimates were 74.7 (SD = 61.2) and 25.7 (SD = 16.4), respectively (Table 4). Spearman's correlation coefficients were calculated for DERM–TVS and DERM–CBA showing good correlation between the methods ($\rho = 0.69$, $P < 0.01$ and $\rho = 0.67$, $P < 0.01$, respectively). When examining more closely the ranking of DERM, TVS and CBA, 75% of the applications (24 of 32) were ranked within the range of 1–5 ranks of difference (Table 5). However, in 16% (5 of 32), the exposures were ranked differently (>10 ranks), i.e. applications ranked as representing high exposure

Table 5. Values and ranks of the determinants of DERM, the total visual score (TVS) and the CBA for 32 observed applications

Application	DERM[a]		TVS		CBA	
	Values	Rank	Values	Rank	Values	Rank
1	33.0	25	78.5	21	33.5	24
2	55.0	31	171.3	30	52.1	31
3	17.7	5	11.4	4	8.4	7
4	57.0	32	270.1	32	65.8	32
5	24.0	17	59.8	16	21.7	14
6	51.0	30	151.0	29	45.9	28
7	22.2	13	56.1	14	16.3	10
8	17.6	4	18.6	8	8.0	6
9	27.9	22	58.2	15	21.1	13
10	21.7	12	65.3	17	26.0	20
11	23.3	14	35.8	9	16.5	11
12	21.2	11	53.7	13	27.0	21
13	23.7	16	71.8	19	21.8	15
14	19.3	9.5	18.0	7	10.0	8
15	24.4	18	88.9	22	24.1	19
16	27.0	21	10.7	3	6.7	4
17	39.9	29	97.3	24	51.2	30
18	28.0	23	172.2	31	45.0	27
19	17.4	3	101.1	25	32.4	23
20	25.5	20	16.1	6	5.8	2
21	38.4	28	113.0	26	49.0	29
22	23.4	15	94.8	23	31.8	22
23	25.2	19	74.1	20	22.9	16
24	35.2	27	150.6	27	42.2	26
25	9.8	1	9.6	2	7.8	5
26	18.0	7.5	36.7	10	15.3	9
27	28.2	24	151.0	28	42.0	25
28	18.0	7.5	70.1	18	23.9	17
29	33.3	26	39.5	11	18.0	12
30	19.3	9.5	40.5	12	24.0	18
31	17.9	6	11.6	5	6.0	3
32	13.6	2	0.5	1	0.5	1

[a]DERM–TVS Spearman's $\rho = 0.69$, $P = 0.000$; DERM–CBA $\rho = 0.67$, $P = 0.000$.

with DERM (3 of 6) were ranked as low exposure with TVS or CBA and vice versa (2 of 6).

DISCUSSION

In this paper, we present a pesticide exposure assessment model based on determinants of dermal exposure to be used in developing countries, where the lack of well-trained analysts and industrial hygienist does not always allow the use of quantitative methods. This model is a combination of a checklist and a rating method; in other words, a list of determinants is evaluated with the help of a simple algorithm. The model was developed to help occupational health and safety personnel with limited resources to assess dermal exposure to pesticides, prioritize further measurements and define intervention programs.

According to Schneider *et al.* (2000), a measurement strategy for dermal exposure assessment should include a structured semiquantitative assessment. However, validated semiquantitative DREAMs for pesticides applicable in developing countries are to our knowledge non-existent. In contrast, in Europe, for instance, models to predict exposure to pesticides or to chemicals in general have been proposed since the early 1990s. Only two of them refer to dermal exposure, although to chemicals in general: the RISKOFDERM model (van Hemmen *et al.*, 2003) and the DREAM model (van Wendel de Joode *et al.*, 2003). The RISKOFDERM is based on rough categorization of tasks and situations different from those present in developing countries, while the DREAM is also based on situations not previously identified in developing countries. Marquart *et al.* (2003) emphasized that models should be based on actual determinants of exposure rather than on rough categorization of tasks or unclear situations. In the US, Stewart *et al.* (2001) proposed a model for assessing occupational pesticide exposures of farm workers using determinants of exposure identified in the literature. Again, the determinants used to develop this model are not relevant to conditions of exposure in developing countries.

Validation of DERM is still incomplete. Very few quantitative exposure studies have ever been completed in developing countries, especially those describing determinants of exposure, providing little data for comparison. For this reason, we decided to compare our semiquantitative methodology with data obtained using the TVS in Aragón's modifications (Aragón *et al.*, 2006) on the same population. The Aragón's modifications of the TVS were evaluated for reliability and have proved to be reliable for assessing dermal exposure to pesticides, resulting of high consistency (Aragón *et al.*, 2004).

The DERM, TVS and CBA showed a good level of agreement (DERM–TVS: $\rho = 0.69$, $P = 0.000$ and DERM–CBA: $\rho = 0.67$, $P = 0.000$). This result is a slightly higher than that of a study comparing the performance of DREAM with the video imaging technique for assessing dermal exposure (VITAE), where the levels of, and factors affecting, dermal and inhalation exposure to semisynthetic metal working fluids were assessed (van Wendel de Joode *et al.*, 2005). The correlation between DREAM and VITAE was $r = 0.57$ ($P < 0.01$). Even though both DERM and DREAM are based on determinants of dermal exposure, DERM uses determinants that are specific for the scenario under study, which probably explains the better agreement between DERM and the TVS. As explained in the Methods, we did not use the comprehensive list of determinants from our previous study, but we included the most important (Blanco *et al.*, 2005) for this group of farmers. Nevertheless, this list of determinants may be modified in the future as the relevance of the exposure determinants changes (for instance, due to control efforts). On the other hand, DERM's algorithm is simpler than the one used in DREAM, in which the use of computerized programs for score calculations is necessary; DERM scores may be calculated manually and right in the field. Thus, DERM promises to be a reliable and easy-to-use method to assess dermal exposure to pesticides in scenarios that are specific to developing country.

Even though a good correlation was reached between the DERM model and both TVS and CBA, in three pesticide applications DERM estimated a higher exposure and in two a lower exposure compared to TVS (and CBA). By thoroughly scrutinizing videotapes of each application, we found a likely explanation for these lower/higher exposure estimates by TVS. When low TVS estimate was obtained, farmers wore clothing that was loose on the body, which probably prevented the permeation of the fluorescent tracer through the clothing. In addition, the duration of the exposure was shorter (an average of 22 versus 47 min) and in turn the time for the tracer to get through clothing.

In both cases where a high TVS estimate was obtained versus a low DERM, crops were >80 cm and wet from morning dew or night rain. Thus, water on the foliage soaked the clothing allowing a more intense permeation of the fluorescent tracer, which reflected in larger and more intense depositions. We should consider in further models how to include soaked clothes. The penetration of clothes depends on several parameters such as type of fabric, fabric thickness, fiber density, water vapor transmission and air permeability among others (Jain and Raheel, 2003). Csiszar *et al.* (1998) reported that cotton and cotton/polyester fabrics, which are the common fabrics in work clothing sold in Nicaragua, absorbed and retained 85–89% of the pesticide—methyl parathion—for >8 h. However, these authors did not report how this parameter can change as a function of water vapor transmission and other parameters. Currently, inclusion of these factors as determinants of exposure would make the model proposed here too complex for practical use.

The determinants with the highest values were mainly related to the work practices (nozzle height, spraying against the wind and splashing on hands), worksite conditions (height of the crop) and equipment (leaking backpack). These determinants can be used to design priorities for intervention programs or to define monitoring programs. For example, the data on the importance of splashes on the hands can induce modifications of the way the applicators pour water into the backpack sprayer tank while preparing the load to be sprayed (mixing). This finding may help to prioritize adequate control measures and suggests that interventions should focus on these determinants (work practices and condition of spray equipment). In addition, the model can be useful to define 'similar exposure groups' for exposure assessment, as recommended by Stewart and Stenzel (2000) that determinants of exposure should be used to identify individuals with similar exposure profiles. Thus, highly exposed workers may be differentiated from low exposed and, consequently, strategies for sampling and measuring exposure levels defined.

DERM might be useful for epidemiological studies as a measure of exposure, though this is not the main goal of the model. For example, these estimates may be combined with the number of applications per year to estimate accumulated lifetime exposure while evaluating cancer or other chronic disease risks. In such a case, it would be necessary to have in mind the relevant pesticides and to identify and validate the main determinants for the population of interest.

In conclusion, DERM promises to be a low-cost easy-to-use method for assessment of exposure to pesticides in developing countries, though further evaluation of reliability and validity of the method is needed. DERM identifies the determinants with the most important influence on the exposure and the farmers with the highest exposure. It identifies farmers with dangerous contact with the pesticides due to work conditions and practices. This can be used to design monitoring programs, define priorities for intervention programs and develop further exposure assessment strategies for an in-depth evaluation of exposure. Finally, we believe that DERM should be used in combination with the fluorescent tracer technique in educational programs addressed to diminish exposure or eliminate risky work practices.

FUNDING

Swedish International Development Cooperation Agency/Department for Research Cooperation.

Acknowledgements—The authors thank all the members of Center for Research on Health, Work and Environment who were involved in gathering data for this project, for their commitment. The authors also thank Timo Partanen for his helpful advice concerning the model.

APPENDIX

An example

To exemplify the DERM estimation process, we chose the farmer with the highest estimate, so most of the determinants could be explained. This farmer sprayed pesticide on his crop of 1.4 Ha of land. He prepared each load of pesticide dilution to be sprayed (a total of 3) by pouring the pesticide formulation

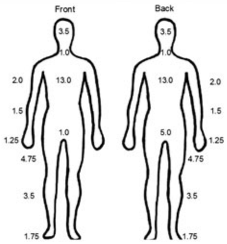
Table A1. Example of the evaluation of a pesticide application using the DERM

Determinants of dermal Exposure Ranking Method (DERM)

File's code: ____________ Farmer ID: ________ Date: ____________

Determinants* / Score to be assigned according to level of analysis	Level of Analysis: Transport (T): Transfer from: Previously contaminated surfaces	Recently contaminated surfaces	Deposition	Emission	Area of body surface (A)[§]: 0-20%	21-40%	41-60%	61-80%	81-100%	Not applicable: Low	High	Det=TxA
	1	3	4	5	1	2	3	4	5	Low	High	
Sprayed surface (Ha)	If <= 0.7 Ha then mark "Low", else mark "High"									1	2	2
Height of the crop		3				2						6
Leaking backpack												0
Volume of sprayed dilution	If <= 30 lts then mark "Low", else mark "High"									2.5	5	5
Nozzle height (cm)			4			2						8
Spraying in front				5		2						10
Spraying against wind			4			2						8
Splash/spill over the pump		3			1							3
Splashes on hands				5	1							5
Splashes on feet				5	1							5
Gross contamination of the hands				5	1							5
											Total=ΣDet	57

Piece of Clothing^	Exposure reduction	Yes	
Long sleeved shirt	0.20		Clothing Protection (C)= 1.0- "Sum of exposure reduction"
Short sleeved shirt	0.15		
Old/overused shirt	0.00	0.0	
Long pants	0.15		
Short pants	0.10		
Old/overused pants	0.00	0.0	
Shoes	0.10	0.0	
Sum of exposure reduction= Σ"Yes"		0.0	C= 1.0-0.0=1



DERM = Σ Det x C = 57

Rater signature: ____________

* Each determinant should be assessed by Transport and Area factors, except for those where otherwise is oriented. The product of the scores for Transport and Area factors should be written down in the last column; then these product should be summed up.
§ Use the inserted figure to estimate the Area (%) of the body surface potentially contaminated by each determinant; for upper and lower extremities the figures represent only one side of the body (right or left).
^ The piece of clothing (shirt and pants) worn by the farmer should be classified in one of the options presented to assign the correspondent score

(~200 ml) right in the tank (20 l volume) of the backpack sprayer and then filled the backpack tank with water by pouring it from a big bucket (20 l). The pouring of the water resulted in splashes on the feet, hands and on the backpack and foaming which he removed using his bare hands. While spraying, the farmer used to walk through recently sprayed plants, which were not >70 cm, and he sprayed the pesticide moving the nozzle in front of him from one side to the other and up and down 20 cm over the height of the crop. The scores assigned to each factor (*T* and *A*) in each determinant (Det_i) and calculations to estimate (i) the determinants' score ($\mathrm{Det}_i = T_i \times A_i$) and their sum ($\Sigma\mathrm{Det}_i$), (ii) the clothing protection factor (*C*) and (iii) the DERM ($C \times \Sigma\mathrm{Det}_i$) are illustrated in Table A1.

The 'sprayed surface' was >0.7 Ha, so a score of 2 is assigned. The height of the crop involved transfer from recently contaminated surfaces ($T = 3$) and ~40% ($A = 2$) of the body surface was contaminated (sum of proportions for feet, legs and thighs) and a Det = 3 × 2 = 6 (see column under the heading 'Det = $T \times A$' in Table A1). The backpack sprayer did not leak, so Det = 0. The volume of the sprayed dilution was >30 l (three tank loads of 20 l) leading to a high exposure and a score of 5. The nozzle height (moving up and down) resulted in drift deposition ($T = 4$) on thighs, legs and feet ($A = 2$) and a Det = 8. Spraying in front resulted in direct emission ($T = 5$) over the thighs, legs and feet ($A = 2$) with Det = 10. Spraying against the wind due to moving the nozzle from one side to the other resulted in deposition ($T = 4$) of the sprayed pesticide onto the face, head, arms and part of the trunk of the farmer, which represented ~40% of the body surface ($A = 2$) and Det = 8. The splashes on the backpack while mixing/loading resulted in pesticide transfer ($T = 3$) onto the back ($A = 1$) of the farmer (Det = 3). The pouring of the water produced splashes ($T = 5$) of the mix on hands ($A = 1$) and feet ($A = 1$) resulting in Det = 5 in both cases. Removing the foam ($T = 5$) with bare hands ($A = 1$) resulted in 'gross contamination of the hands' and Det = 5. Once all the scores have been estimated for each determinant, they are summed up (total = ΣDet, in Table A1).

The farmer was wearing an old/overused T-shirt (exposure reduction = 0.0), old/overused short pants (exposure reduction = 0.0) and no shoes, so the total exposure reduction due to his clothing was 0.0, resulting in a clothing protection factor of 1 (1 − total exposure reduction = 1). The DERM is estimated by multiplying the clothing protection factor (*C*) and the sum of the scores of the determinants (ΣDet) (Table A1).

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