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Assessment of Dermal Pesticide Exposure with Fluorescent Tracer: A Modification of a Visual Scoring System for Developing Countries

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A semi-quantitative dermal exposure assessment method based on visual observations of fluorescence images was presented by Fenske in 1988. We adapted the method to Nicaraguan working conditions and evaluated its performance. Thirty-two farmers applied chlorpyrifos and methamidophos marked with Tinopal CBS-X®. Skin fluorescent depositions were observed with a portable UV lamp in a foldaway darkened room. We modified the two components of the original system—extent by weighting the size of exposed body parts according to total body surface and intensity by establishing criteria for reading the fluorescence images. This resulted in body segment scores (BSSs) for specific body parts as well as two summary measures, contaminated body area (CBA) as the percentage of contaminated skin in relation to total body surface and total visual score (TVS) as an overall score combining extent and intensity of contamination. The scoring of intensity was evaluated with quantitative chemical residue analyses. Hands were the most frequently contaminated, and the back had the highest BSS. The CBA ranged between 1 and 66% and the TVS between 0.5 and 270. The farmer with the highest TVS scored 60% of the maximum possible. Residues increased with increasing fluorescence intensities with some misclassification. Fluorescent images reflected work practices and contamination mechanisms. In conclusion, the visual score, as modified by us, provides information on the body segments most contributing to dermal exposure and degree of skin contamination during pesticide applications. Fluorescence patterns reflect exposure routes. The system is low-cost and practical for developing countries. Further improvements are recommended.

Keywords: dermal exposure; developing country; exposure assessment; fluorescent tracer; methods; Nicaragua; pesticides

INTRODUCTION

Fluorescent tracers were first employed in occupational health >20 years ago as a qualitative tool for a dermal exposure study of orchardists (Franklin *et al*., 1981). Since then, different types of fluorescent tracers have been used to estimate dermal exposure (Fenske *et al*., 1986; Roff, 1994; Bierman *et al*., 1998), evaluate performance of protective devices (Fenske, 1988a; Fenske *et al*., 2002), for educational purposes (Houghton *et al*., 1998; Foss *et al*., 2002), and to demonstrate the non-uniformity of dermal exposure (Fenske, 1990). The principle is that a fluorescent tracer is added to a hazardous solution and traced afterwards by means of a UV lamp. These fluorescent compounds have also been examined

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quantitatively with video-imaging to estimate exposure of the entire body surface (Fenske *et al*., 1986; Fenske, 1988b). Between 1988 and 1994 a first and second generation of video-imaging technique for assessing dermal exposure (VITAE) (Fenske *et al*., 1997) and another quantitative technique, the fluorescent interactive video exposure system (FIVES) were presented and improved (Roff, 1994). A drawback of this type of quantitative evaluation is the high cost (Cherrie *et al*., 2000). Video-imaging processors require an infrastructure in the field that goes beyond reasonable research budgets for countries like Nicaragua. Such sophisticated methods are not viable in field situations with limited access to electricity or inadequate roads for transportation of sensitive equipment.

Fenske (1988c) proposed a more accessible semi-quantitative evaluation method based on visual observations of fluorescence images combined with the use of a scoring system, which provides results on-site without chemical analyses. The 'visual scoring system' correlated well with the computerized VITAE system and appeared to be inexpensive and practical. Thus, it was recommended for field studies. However, some adaptations were needed to make it applicable for Nicaraguan working conditions. With this method, Fenske evaluated contamination of face and hands, the body parts most prone to contamination when wearing protective equipment. Nicaraguan subsistence farmers usually do not wear protective clothing, and extensive skin contamination can occur in multiple body parts (Aragón *et al*., 2001). We developed a modified version that allowed the evaluation of the entire body surface, and introduced changes in the recording and scoring of fluorescent images. The aim of this study was to evaluate the performance of this modified version in the context of a developing country.

MATERIALS AND METHODS

The study design and methods have been described in detail in previous papers (Aragón *et al.*, 2004; Blanco *et al.*, 2005). In brief, the study group consisted of subsistence farmers in western Nicaragua, who sprayed their crops with motorized or manual backpack sprayers. None used personal protective equipment. All sprayed barehanded and only five wore shoes. This report includes the data of 32 applications carried out by 30 farmers, who applied chlorpyrifos or methamidophos. Tinopal CBS-X® [disodium 4,4′ –bis(2-sulfostyryl) biphenyl] was used as tracer in this study (260 mg/l). Tinopal was chosen because of its availability in Central America, low cost and water solubility. It does not cause skin sensitization (Bierman *et al*., 1998; Houghton *et al*., 1998) and it is reported to degrade in sunlight by 9.4% in 100 min (Barber and Parkin, 2003). Tinopal has been used in combination with propoxur in a greenhouse study (Bierman *et al*., 1998), to test a new visual scoring technique of dermal contamination among hospital workers (Kromhout *et al*., 2000), and for educational purposes (Foss *et al*., 2002). At the start of the workday, farmers wearing underpants were observed inside a foldaway dark room. The room consisted of wood frame walls and roof, and a black synthetic leather cover that can be put together by means of Velcro® (Fig. 1). A hand held UV lamp (UVP®, model UVSL-26P) without filter was used for illumination. Farmers were offered eye protection. The observation procedure inside the foldaway dark room has been described (Aragon *et al*., 2004). In the field, the tracer was placed into the tank of the backpack by one of the researchers before the farmer poured the concentrated pesticide, which was not traced. Farmers applied the pesticide as usual. Immediately after finishing the application, fluorescent depositions were videotaped in the darkened foldaway room. After application some farmers had dirt on their hands and, in particular, on their feet. However, the fluorescent tracer could be observed. Damp skin because of high temperature is unlikely to mask the fluorescence, since Tinopal binds strongly to the skin and cannot be easily removed by rinsing or washing (Bierman *et al*., 1998).

Fig. 1. Foldaway dark room for fieldwork.

Table 1. Modifications of Fenske's (1988) visual scoring system with fluorescent tracer

Fenske's original visual scoring system	Modifications in the present study
Computer equipped dark room	Foldaway dark room (Fig. 1)
Large fixed UV lights for illumination	Portable UV lamp with battery
Use of photographs for scoring	Use of videotapes for scoring
7 body segments (face and hands, 9% total body surface)	31 body segments (91% total body surface)
No scoring of areas without fluorescence	Areas without fluorescence scored as 0
Scores identical for all body segments, independent of size	Body segment scores weighted by size
Qualitative reading of intensity	Qualitative reading of intensity with guidelines for deposition patterns

The modified visual scoring system

The original visual scoring system was based on a matrix where the ordinate represented the extent, and the abscissa the intensity of the fluorescence as described previously (Fenske *et al*., 1988; Aragón *et al*., 2004). Table 1 summarizes the modifications made to the original method.

Body surface segments

To evaluate the whole body surface, the body was divided into face, neck, trunk, upper arms, forearms, hands, thighs, legs and feet. Each body segment was subsequently subdivided into front and back, except for the face, which was divided into three sections, in accordance with Fenske's (1988c) method. The back of the head was not examined and the soles of the feet were included only after the first 11 farmers had been examined. For ethical reasons, buttocks and genitalia remained covered and could not be considered for scoring. This resulted in 29 body segments scored for all subjects and 31 body segments scored for 21 subjects, accounting for 90% of the total body surface area.

Scoring extent of tracer depositions

To quantify the extent of fluorescence on the surface is a rather straightforward process. Considering that body segments have different sizes, we modified the scoring system by weighting the extent scores of the specific body segments by their proportion of the whole body. The weights are based on the percentages used on the Lund and Browder (L&B) chart for each body segment to estimate proportion of affected body surface in burned patients (Lund and Browder, 1944) (Table 2). The weighted extent score is computed using the following equation:

$$\mathrm{WES} = \%_{\mathrm{BS}} \times \frac{\mathrm{ES_F}}{5},$$

where WES is the weighted extent score, $\%_{\mathrm{BS}}$ is the L&B percentage for a body segment, and $\mathrm{ES_F}$ is Fenske's extent score. The denominator is the maximum possible extent of Fenske's score.

Scoring intensity of tracer deposition

Since there were no model images available for scoring intensity, this was more difficult than scoring extent. To get acquainted with a contamination gradient we tested different volumes of tracer on clothes and performed assays with a backpack sprayer, including videotaping and observations on a farm simulating a pesticide application. Low intensity (1) was considered if the image was opaque, moderate (3) if the appearance was milky with some brightness, and high (5) in the case of strong bright images. These images have different patterns such as smears, mists and splashes. Therefore, guidelines were created to standardize pattern observation with intensity gradient (Appendix 1). Additionally, reliability was tested with five independent raters in a subgroup of five farmers. A two-way intraclass correlation coefficient gave a satisfactory result of 0.75 for the visual scores. However, ICC was higher (0.80) for extent and lower (0.54) for intensity (Aragón *et al*., 2004).

Body segment score

The body segment scores (BSSs) were the product of the WES and the intensity score (IS) for specific body segments (BSS = WES × IS). Table 2 shows the maximum possible weighted scores for the specific body segments. The maximum scores now varied between 5 for the smallest segments (back and front of the neck) and 65 for the largest segment (posterior trunk).

Contaminated body area and total visual score

The WES of the body segments are equivalent to the contaminated percentages in relation to the total body surface and their sum provided a rough estimate of the contaminated proportion of the total body surface, the contaminated body area (CBA).

The sum of the 31 weighted BSS generated an overall average contamination score for each farmer, the total visual score (TVS). In two previous reports, we used the sum of the fluorescent deposition scores of all body segments without consideration of their surface area (Aragón *et al*., 2004; Blanco *et al*., 2005). Without weight, the TVS could theoretically range from 0 to 775, and with weight from 0 to 453. The correlation between non-weighted and weighted TVS was high (Spearman 0.92).

Table 2. Weights for body segments (Lund and Browder, 1944, Chart for burns), highest possible values of body segment scores (BSSs), percent of farmers with fluorescence deposition, mean and range of BSS among contaminated farmers

Body surface area (BSA)	Proportion of total body surface (L & B)	Body segment	Body segment percentage according to BSA	Highest possible BSS	Proportion of farmers with contamination	BSS among contaminated farmer	
						Mean (SD)	Range
Head	7	Right side face	1.17	5.9	34.4	0.7 (0.3)	0.2–1.2
		Front side face	1.17	5.9	62.5	0.9 (0.8)	0.2–3.5
		Left side face	1.17	5.9	31.3	0.7 (0.6)	0.2–2.3
		Back of the head	3.50 (Not examined)				
Neck	2	Front	1	5	31.3	0.5 (0.4)	0.2–1.2
		Back	1	5	25.0	0.9 (1.0)	0.2–3.0
Trunk	26	Anterior	13	65	53.1	9.2 (9.9)	2.6–41.6
		Posterior	13	65	75.0	28.6 (22.5)	2.6–65.0
Right buttock	2.5		2.5 (Not examined)				
Left buttock	2.5		2.5 (Not examined)				
Right upper arm	4	Front	2.0	10	18.8	2.5 (3.0)	0.4–8.0
		Back	2.0	10	25.0	0.7 (0.6)	0.4–2.0
Left upper arm	4	Front	2.0	10	34.4	2.0 (1.9)	0.4–6.4
		Back	2.0	10	37.5	3.1 (2.5)	0.4–8.0
Right lower arm	3	Front	1.5	7.5	71.9	2.0 (1.8)	0.3–6.0
		Back	1.5	7.5	62.5	1.6 (1.5)	0.3–4.8
Left lower arm	3	Front	1.5	7.5	75.0	2.0 (1.8)	0.3–6.0
		Back	1.5	7.5	62.5	2.3 (1.7)	0.3–6.0
Right hand	2.5	Palm	1.25	6.3	93.8	2.7 (2.2)	0.3–6.3
		Dorsum	1.25	6.3	87.5	2.2 (1.8)	0.3–5.0
Left hand	2.5	Palm	1.25	6.3	90.6	3.3 (1.9)	0.3–6.3
		Dorsum	1.25	6.3	90.6	2.8 (1.9)	0.2–6.3
Right thigh	9.5	Front	4.75	23.8	31.3	6.8 (6.1)	1.0–19.0
		Back	4.75	23.8	18.8	6.7 (5.0)	1.9–15.2
Left thigh	9.5	Front	4.75	23.8	53.1	6.9 (5.2)	1.0–19.0
		Back	4.75	23.8	34.4	5.3 (5.8)	1.0–19.0
Right leg	7	Front	3.5	17.5	40.6	10.1 (5.1)	3.5–17.5
		Back	3.5	17.5	43.8	4.6 (5.4)	0.7–14.0
Left leg	7	Front	3.5	17.5	56.3	8.2 (5.6)	0.7–17.5
		Back	3.5	17.5	46.9	5.7 (5.8)	0.7–17.5
Right foot	3.5	Front	1.75	8.8	71.9	4.9 (3.7)	0.4–8.8
		Back (n = 21)	1.75	8.8	52.4	3.7 (2.9)	0.4–8.8
Left foot	3.5	Front	1.75	8.8	65.6	5.6 (3.3)	0.4–8.8
		Back (n = 21)	1.75	8.8	57.1	3.9 (3.2)	0.4–8.8
Genitalia	1		1.00 (Not examined)				
Total	100	Total	90.5	453		74.7 (61.2)	0.5–270.0

Skin wiping according to fluorescent intensities

After observation and videotaping of the subjects, skin wipes were used to remove the residues of pesticides from skin areas with different fluorescence intensity. A sample of a non-fluorescent area was taken and, depending on the range of intensities observed, 1 to 5 additional samples. While one researcher illuminated, another wiped the area with 8.5 × 5 cm single gauze impregnated with 2 ml isopropanol. The gauze was then introduced in a vial, labelled accordingly, and immediately stored in a cooler for transportation to the laboratory. A transparent plastic foil was placed on the wiped skin directly after the wiping. The wet image left by the wipe was drawn with a waterproof pen. The encircled area on the plastic foil was cut out and weighed to calculate the surface area in cm^2. This procedure was performed for 24 farmers ending up

with 110 samples. Since four farmers applied a mixture of the two studied pesticides (17 samples), this resulted in 127 samples of pesticide residues analysed. The samples were taken from any body part except the hands, since all of them were wiped and would be reported separately. At the laboratory, samples were stored in a freezer at −20°C previous to analysis. They were extracted with acetone. The analysis was performed with capillary gas chromatography. Chlorpyrifos analysis was conducted in Nicaragua using an electron capture detector and analyses for methamidophos were conducted in Costa Rica with a nitrogen-phosphorus detector. The quantification limit (LOQ) was 0.04 µg for chlorpyrifos and 0.1 µg for methamidophos.

Data analyses

Percentages of contaminated farmers were calculated for body segments each, and the body segments most and least prone to contamination were identified. Means were used as measures of central tendency, and standard deviations and range as measures of spread for CBA, BSS (only scores >0) and TVS. Spearman correlation coefficients were calculated for chlorpyrifos and methamidophos residues and the six categories of intensity scores (0–5). The intensity gradient was regrouped into three broader categories of clean (0), low to moderate (1–3) and high (4–5) fluorescent intensity.

For each of these categories mean values of chlorpyrifos and methamidophos residues (µg/cm^2) detected on the wiped areas were calculated, and adjusted for concentration of pesticide spray solution. For those results with non-detectable residues, we assigned values corresponding to the LOQ divided by the wiped area (13% of all samples).

RESULTS

The pre-spraying videotapes showed only minimum fluorescence on one farmer's ear. After spraying, 100% of the farmers had fluorescent depositions. The number of contaminated body segments per farmer ranged from 2 to 28. Conversely, there was not a single body segment clean for all farmers. The CBA ranged from 1 to 66% of the total body surface, with a mean of 25.7 (SD, 16.4). Depositions were most frequently observed on the front and back of hands (>87% of the farmers), the front side of the left forearm (75%), and the back of the trunk (75%). Depositions were less frequently observed on the front side of the right upper arm (19%) and the back of the right thigh (19%). The highest BSS among contaminated farmers, by far, was observed for the back (mean 28.6, range 2.6–65.0). The right and left sides of the face, the front of the neck and back of the right upper arm had, in general, the lowest scores.

The mean TVS was 74.7, ranging between 0.5 and 270. The highest TVS represented 60% of the maximum possible (Table 2).

Figure 2 shows how increasing levels of skin residues correlate with increasing fluorescence intensity observed on the skin (Spearman correlation coefficient = 0.63, both for chlorpyrifos and methamidophos). Mean, median and maximum levels of residues of both insecticides clearly increase with increasing intensity, even after adjusting for the concentration in the spray mixture (Table 3). However, some samples of skin areas considered as clean contained residues and, conversely, no or very low residues were detected in some samples in the moderate and high fluorescence intensity categories. There were 17 samples with non-detectable levels (7% of the chlorpyrifos and 18% of the

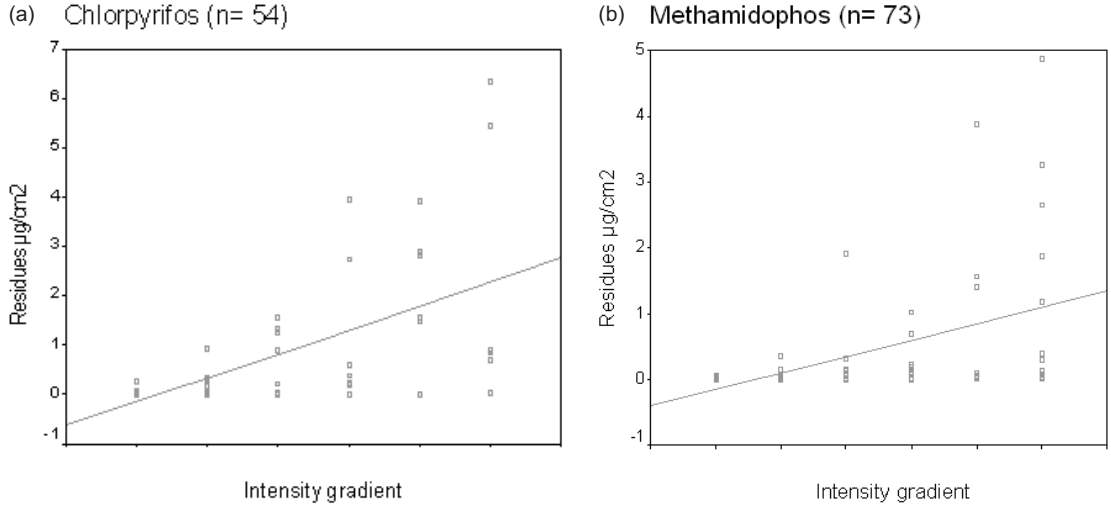

Fig. 2. (**a**) and (**b**) Correlation of pesticides residues with intensity gradient (clean = 0, low to high = 1–5). Spearman's rho = 0.63 for chlorpyrifos and methamidophos.

Table 3. Residues of chlorpyrifos and methamidophos (μg/cm^2) according to intensity gradient of fluorescent tracer on skin

Intensity	Mean (SD)	Median	Range	Adjusted by pesticide concentration in spray mixture
				Mean (SD)
Chlorpyrifos (n = 54)				
Clean (n = 13)	0.04 (0.07)	0.03	<LOQ–0.27	0.01 (0.03)
Low and moderate (n = 27)	0.59 (0.93)	0.21	<LOQ–3.97	0.65 (0.31)
High (n = 14)	4.60 (6.60)	2.19	0.01–23.40	2.14 (2.72)
Methamidophos (n = 73)				
Clean (n = 16)	0.01 (0.02)	0.01	<LOQ–0.06	0.01 (0.01)
Low and moderate (n = 38)	0.17 (0.35)	0.07	<LOQ–1.92	0.06 (0.11)
High (n = 19)	1.09 (1.49)	0.21	0.02–4.88	0.41 (0.55)

Analysis by gas chromatography (n = 127). Level of quantification (LOQ) chlorpyrifos 0.04 μg; LOQ methamidophos 0.1 μg.

methamidophos samples). Of these, 10 corresponded to non-fluorescence, 4 to low fluorescence, and 3 to low-moderate fluorescence intensity.

The most frequent contamination pattern was smear followed by splash and then mist; furthermore, combinations of patterns were often observed. As illustrations of how these patterns are indications of pathways of exposure, Fig. 3 (sequence a, b and c) shows the transfer of the contaminant from the source to the skin by direct contact and redistribution from one part to another part of the skin (smears), and Fig. 4 (sequence a and b) demonstrates the transfer of the contaminant from the source to the skin via emissions into the air and deposition on the face (mist).

DISCUSSION

We made a number of modifications to Fenske's visual scoring system for dermal exposure to adapt it to developing country conditions. We extended and deepened the two components of the scoring system: extent and intensity of fluorescent depositions. The modifications target the body segments that contribute most to the total dermal exposure and those that are more prone to contamination. The percentage of contaminated body surface and the overall average contamination for individual farmers can be estimated. The method indicates pathways of dermal contact.

Higher residues in areas with high intensity images and vice versa were found (Table 3 and Fig. 2), but detectable residues were found also in clean areas and low levels of residues in high intensity areas. There are many factors possibly underlying these inconsistencies. They may be related to the pesticide, the tracer, the skin wipe technique, the videorecording or the scoring of the fluorescence images. The concentration of the pesticide in the spray mixture, physical and chemical properties of the pesticide such as evaporation and skin penetration, and the time of residence of the pesticide from its deposition to the moment of sampling may play a role. The concentration of the tracer was constant for all farmers of this study, whereas the pesticide concentration varied considerably. This was accounted for (Table 3). The hydrophilic methamidophos is an unstable compound (EFSA, 2004), while the lipophilic chlorpyrifos can remain on the skin for hours (Meuling *et al*., 2005). This may explain why we found fewer samples below the level of quantification but with higher levels of residues for chlorpyrifos than for methamidophos.

Tracer intensity may overestimate the amount of residues because tracers bind strongly to the skin, whereas pesticides may be removed by washing or perspiration, can evaporate or be absorbed (Cherrie *et al*., 2000). Tracer intensity may also underestimate factual pesticide exposure. Fabrics can constitute a differential barrier for tracer and pesticide (Schneider *et al*., 1999). Bierman *et al*. (1998) reported that only 12% of Tinopal deposited on clothes penetrated through clothing to reach the skin, whereas penetration of pesticides may be much higher. In addition, deposition of the tracer on the skin may be so high that fluorescence is no longer proportional to the amount of tracer (quenching) (Fenske, 1988a). Thus, fluorescence intensity from a single splash may be comparable with the intensities obtained from constant dripping of a leaking pump. Also, the tracer is subject to degradation. Exposure to sunlight can reduce the intensity of the fluorescent deposits by 9% per hour (Barber and Parkin, 2003). The longest application time in our study was almost 3 h, which may imply that fluorescent deposits may have faded away by as much as 25%. The majority of applications lasted less than an hour and started in the early morning, reducing such degradation effect. In addition, there may be exposure to untraced pesticide, for example in previously contaminated clothes. In our study the concentrate was not traced and residues were, therefore, found in non-fluorescence areas.

The skin wipe technique may be limited by low recovery efficiency (Brouwer *et al*., 2000). Geno (1996) recovered 104% of chlorpyrifos, but his

Fig. 3. (**a**) Leakage of the spray head (**b**) Farmer fixing the spray head after trying to control the leakage with his hands (**c**) After application: Fluorescent images on farmer's left hand.

Fig. 4. (**a**) Wind blowing spray cloud, (**b**) After application: Mist image on the left side of farmer's face.

experiment did not allow for residence time of the pesticide on the skin. Others recovered between 36 and 92% from other pesticides (Brouwer *et al.*, 2000). Fenske *et al.* (1999) compared three methods having the lowest recovering efficiency with the skin wipes (6.4-fold lower than hand wash). Finally, skin residues might not be a real gold standard, since they are prone to systematic and random measurement error (Armstrong, 1998) and depend on the solvent used for the contaminant.

Deficiencies in videorecording technique and difficulties in reading of the fluorescent images, in particular the intensity, may have contributed to the inconsistencies. Scoring extent was more reliable than intensity, especially for low intensity images (Aragón *et al*., 2004). This was most evident for smear images. A reliability study (Aragón *et al*., 2004) showed that smear patterns at low intensity may be interpreted as absence of fluorescence. Lack of a filter on our video camera or the UV light source could have contributed to difficulties in observing low fluorescence.

Despite limitations, the modified visual scoring system is a major step forward in understanding exposure mechanisms. A particular strength is the use of BSS to evaluate the entire body. Hands have been previously considered as an important, if not the most important, contributor to total dermal pesticide exposure (Curwin *et al.*, 2003; Machera *et al*., 2003). In our conditions, however, even though hands were most frequently exposed, leaking backpacks with badly sealed lids and overfilled tanks accounted for a frequency of contamination of the back almost as high as for the hands, and the BSS of the much larger back was considerably higher. Also the feet and front of lower legs were identified as important contribu-

tors to total dermal exposure in unprotected sprayers, which contrasts with other findings (Machera *et al.*, 2003; van der Jagt *et al*., 2004). The relatively low contamination rate of the back upper right arm (25%) was restricted to the motorized backpack applicators (0% motorized versus 62% manual). An apparent explanation is that the hose of the motorized backpacks is located at the waist but passes behind the right arm for manual backpacks (Fig. 3a). Such insights are useful for intervention.

Another strength is the identification of contamination patterns. The fluorescent distribution pattern gave clues of work practices that influence dermal exposure, such as direct transfer from the source to the skin, immersion into the substance and redistribution from one part of the skin surface to another (Schneider *et al*., 1999) (Figs 3 and 4).

In conclusion, the amount of pesticide residue was proportional to the fluorescence intensity gradient, indicating a satisfactory performance of our modified visual scoring system. In the context of poor subsistence farmers in poor countries like Nicaragua, the evaluation of the entire body and most body segments is an advantage that outweighs the above discussed limitations, providing a basis for different types of interventions. The system is cheap and feasible in the field situations in developing countries with limited infrastructures, and can be used after short training. Further improvements should be made, including standardization of the illumination, use of a filter for the video camera, use of a digital camera, and comparisons with pre-exposure videotapes for those body segments with apparent non-fluorescence.

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APPENDIX 1. GUIDELINES FOR SCORING INTENSITY IN ACCORDANCE TO PATTERN OF FLUORESCENT DEPOSITION

Images of smear (commonly related to direct transfer from the source to skin and a contaminated surface to skin or redistribution):

These patterns include, for example, images of the rubbing of the tank or the harness of the backpack on the skin, the immersion of a finger into the pesticide mixture, or the passage of the substance through clothing.

- Low: Fine layer distributed uniformly on the skin, similar to an application of talc powder. The pattern is opaque and only slightly perceived. These contamination patterns are easily overlooked without clean areas at the side. They may be related to the protective barrier of thick clothes and short spraying time. They can be observed when workers dress in "jeans" or a loose shirt.
- Moderate: Several fine layers, one over the other with little brightness or without brightness but clearly distinguishable. The pattern resembles the application of a milky lotion on the skin. There are some bright areas but the image is predominantly opaque. It can be observed when workers use thin clothes or on uncovered body areas.
- High: Bright, milky image. The pattern is mostly related to gross deposition of the substance to the skin, immersion of the body part into the solution, or splashes that have spread out over the skin.

Images of mist (emission from the source directly deposited on the skin surface, frequently on uncovered areas):

- Low: Sparsely distributed fluorescent dots.
- Moderate: More condensed fluorescent dots with predominance of opaque images and few bright spots.
- High: Numerous highly condensed bright spots.

Images of splashes (emission from the source to the skin surface):

- Moderate: Clear but opaque splash images on the skin.
- High: Bright splash images on the skin.

REFERENCES

Aragón A, Aragón C, Thörn Å. (2001) Pest, peasants and pesticides in the pacific plain of Nicaragua. Int J Occup Environ Health; 7: 295–302.

Aragón A, Blanco L, López L *et al*. (2004) Reliability of a visual scoring system with fluorescent tracers to assess dermal pesticide exposure. Ann Occup Hyg; 48: 601–6.

Armstrong BG. (1998) Effect of measurement error on epidemiological studies of environmental and occupational exposures. Occup Environ Med; 55: 651–6.

Barber J, Parkin C. (2003) Fluorescent tracer technique for measuring the quantity of pesticide deposited to soil following spray applications. Crop Prot; 22: 15–21.

Bierman EPB, Brouwer DH, Van Hemmen JJ. (1998) Implementation and evaluation of the fluorescent tracer technique in greenhouse exposure studies. Ann Occup Hyg; 42: 467–75.

Blanco LE, Aragón A, Lundberg I *et al*. (2005) Determinants of dermal exposure among Nicaraguan subsistence farmers during pesticide applications with backpack sprayers. Ann Occup Hyg; 49: 17–24.

Brouwer DH, Lansink CM, Cherrie JW *et al*. (2000) Assessment of dermal exposure during airless spray painting using a quantitative visualisation technique. Ann Occup Hyg; 44: 543–9.

Cherrie J, Brouwer D, Roff M *et al*. (2000) Use of qualitative and quantitative fluorescence techniques to assess dermal exposure. Ann Occup Hyg; 44: 519–22.

Curwin BD, Hein MJ, Sanderson WT *et al.* (2003) Acephate exposure and decontamination on tobacco harvesters' hands. J Expo Anal Environ Epidemiol; 13: 203–10.

EFSA Journal (2004) Opinion of the scientific panel on plant health, plant protection products and their residues on a request from the commission related to the evaluation of methamidophos in toxicology in the context of Council Directive 91/414/EEC; 95: 1–15. Available from: http://www.efsa.eu.int

Fenske RA. (1988a) Comparative assessment of protective clothing performance by measurement of dermal exposure during pesticide applications. Appl Ind Hyg; 3: 207–13.

Fenske RA. (1988b) Correlation of fluorescent tracer measurements of dermal exposure and urinary metabolite excretion during occupational exposure to malathion. Am Ind Hyg Assoc J; 49: 438–44.

Fenske RA. (1988c) Visual scoring system for fluorescent tracer evaluation of dermal exposure to pesticides. Bull Environ Contam Toxicol; 41: 727–36.

Fenske RA. (1990) Nonuniform dermal deposition patterns during occupational exposure to pesticides. Arch Environ Contam Toxicol; 19: 332–7.

Fenske RA, Birnbaum SG. (1997) Second generation video imaging technique for assessing dermal exposure (VITAE System). Am Ind Hyg Assoc J; 58: 636–45.

Fenske RA, Wong SM, Leffingwell JT *et al.* (1986) A video imaging technique for assessing dermal exposure. II. Fluorescent tracer testing. Am Ind Hyg Assoc J; 47: 771–5.

Fenske RA, Birnbaum SG, Methner MM *et al.* (2002) Fluorescent tracer evaluation of chemical protective clothing during pesticide applications in central Florida citrus groves. J Agric Saf Health; 8: 319–31.

Fenske RA, Simcox NJ, Camp JE, Hines CJ (1999). Comparison of three methods for assessment of hand exposure to azinphos-methyl (Guthion) during apple thinning. *Appl Occup Environ Hyg*; **14**: 618–23.

Foss C, Allen E, Fenske RA *et al.* (2002) Comparison of live skit and video delivery styles using presentations with and without fluorescent dyes at pesticide applicator training for promoting of self-protection from dermal exposure. J Pest Saf Ed; 4: 2–9.

Franklin CA, Fenske RA, Greenhalgh R *et al*. (1981) Correlation of urinary pesticide metabolite excretion with estimated dermal contact in the course of occupational exposure to Guthion. J Toxicol Environ Health; 7: 715–31.

Geno PW, Camann DE, Harding HJ *et al.* (1996). Handwipe sampling and analysis procedure for the measurement of dermal contact with pesticides. Arch Environ Contam Toxicol; 30: 132–8.

Houghton D, Archibald B, Solomon K. (1998) Review of video imaging techniques for estimating dermal exposure to pesticides. In Taylor ED and Francis, editors. Occupational hazards of pesticide exposure. Sampling, Monitoring, Measuring. Philadelphia.

Kromhout H, Hoek F, Uitterhoeve R *et al.* (2000) Postulating a dermal pathway for exposure to anti-neoplastic drugs among hospital workers. Applying a conceptual model to the results of three workplace surveys. Ann Occup Hyg; 44: 551–60.

Lund CC, Browder NC. (1944) The estimation of areas of burns. Surg Gynecol Obstet; 79: 352–8.

Machera K, Goumenou M, Kapetakanis E *et al.* (2003) Determination of potential dermal and inhalation operator exposure to malathion in greenhouses with the whole body dosimetry method. Ann Occup Hyg; 47: 61–70.

Meuling W, Ravensberg L, Roza L *et al.* (2005) Dermal absorption of chlorpyrifos in human volunteers. Int Arch Occup Environ Health; 78: 44–50.

Roff MW. (1994) A novel lighting system for the measurement of dermal exposure using a fluorescent dye and an image processor. Ann Occup Hyg; 38: 903–19.

Schneider T, Vermeulen R, Brouwer DH *et al*. (1999) Conceptual model for assessment of dermal exposure. Occup Environ Med; 56: 765–73.

van der Jagt K, Tielemans E, Links I *et al.* (2004) Effectiveness of personal protective equipment: relevance of dermal and inhalation exposure to chlorpyrifos among pest control operators. J Occup Environ Hyg; 1: 355–62.