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DERMAL EXPOSURE DETERMINANTS - A PESTICIDE EXPOSURE ASSESSMENT APPROACH FOR DEVELOPING COUNTRIES

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To my beloved wife, Edipcia.
Your support and encouragement were the motor for this work.

ABSTRACT

Background: We know little about the levels of exposure to pesticide in subsistence farmers mainly because of lack of easy to use and low cost pesticide exposure assessment methods.

Aim: This thesis aimed to develop a semi-quantitative approach to assess dermal exposure to pesticides relevant for conditions in developing countries.

Methods: Work was carried out with two groups of subsistence farmers. A visual scoring system, based on the assessment of the extent and intensity of fluorescent images, was modified for Nicaraguan conditions and used to estimate the level of exposure to pesticides of the first group of 31 subsistence farmers. The performance of the modifications was assessed by comparing visual score estimates with the residues of pesticides in the skin with different fluorescent intensity. Residues were quantified by means of skin wiping of areas with different fluorescent intensity. Further, 32 pesticide applications were observed in order to identify relevant determinants of dermal exposure to pesticides. The relevance of the determinants was assessed by correlation with the visual score estimates. A method to assess exposure to pesticide under conditions of developing countries was developed. The method, called DERM, combined checklist and expert rating methods: the relevant determinants are evaluated using an algorithm based on the type of transport process and the area of body surface affected; clothing was also included as a protection factor. Ten industrial engineers, who worked as occupational hygienists at the Nicaraguan Ministry of Labor, applied the DERM to 5 videotaped pesticide applications of a second group of subsistence farmers. The inter-rater correlation coefficient was estimated to assess the reliability of DERM.

Results: The modifications to the visual scoring system allows identification of the most frequently contaminated body parts (the back of the trunk, the hands and forearms, the front of the legs and the feet) and give some clues on the mechanisms of contamination (transfer of the pesticide while touching contaminated surfaces, deposition from the air, and emissions from the source). The skin wiping confirmed a good performance of the modifications ($r=0.63$). The multistep reduction strategy identified 27 relevant determinants of dermal exposure to pesticide. Work practices, spray equipment, and worksite related determinants explained 52, 33 and 25% of the exposure variability; clothing and hygiene practices were weaker determinants and did not always reduce the exposure. The DERM algorithm performed well against the visual scoring system ($r=0.69$; $p<0.01$), and was reliable (ICC=0.67; $CI_{95\%}=0.37\text{-}0.9$). DERM identified the farmer with the highest exposure and the relevant determinants.

Conclusions: Semiquantitative methods such as the fluorescent tracer and the visual scoring system, and assessment of determinants with a simple algorithm, promise to be good alternatives for exposure assessment in developing countries. The DERM method proved to be reliable and easy to use for the identification of highly exposed farmers and relevant determinants of exposure. Combination of fluorescent tracer technique and DERM may be useful for designing preventive programs to reduce exposure to pesticide.

Keywords: dermal exposure, pesticides, determinants of dermal exposure to pesticides, subsistence farmers, fluorescent tracer, visual scoring system.

LIST OF PUBLICATIONS

This thesis is based on the following studies, which will be referred to by their Roman numerals I-IV:

I. Aragon A, Blanco LE, Funez A, Ruepert C, Lidén C, Nise G, and Wesseling C. (2006) Assessment of Dermal Pesticide Exposure with Fluorescent Tracer: A Modification of a Visual Scoring System for Developing Countries. *Ann Occup Hyg; 50(1): 75-83*

II. Blanco LE, Aragon A, Lundberg I, Wesseling C, and Nise G. (2005) Determinants of Dermal Exposure among Nicaraguan Subsistence Farmers during Pesticide Applications with Backpack Sprayers. *Ann Occup Hyg; 49(1): 17-24*

III. Blanco LE, Aragon A, Lundberg I, Wesseling C, and Nise G. (2008) The Determinants of Dermal Exposure Ranking Method (DERM): A Pesticide Exposure Assessment Approach for Developing Countries. *Ann Occup Hyg; 52(6): 535-44*

IV. Blanco LE, Aragon A, Lundberg I, Wesseling C, and Nise G. Reliability of the Determinants of Dermal Exposure Ranking Method (DERM) to Assess Dermal Exposure to Pesticide. *Submitted*

CONTENTS

LIST OF ABBREVIATIONS

A value	Factor for assessing the Area exposed
BSS	Body Segment Score
CBA	Contaminated Body Area
C value	Factor for assessing the Clothing protection
DERM	Determinants of dermal Exposure Ranking Method
DREAM	DeRmal Exposure Assessment Method
EPA	Environmental Protection Agency
FAO	Food and Agriculture Organization
LOQ	Limit of Quantification
MINSA	Ministerio de Salud (Ministry of Health)
MT/ha	Metric Tons per Hectare
PAHO	Pan American Health Organization
T value	Factor for assessing the type of Transport process
RISKOFDERM	Risk Assessment of Occupational Dermal Exposure
TVS	Total Visual Score
UNAN-León	Universidad Nacional Autónoma de Nicaragua, León) National Autonomous University of Nicaragua at León)
UV	Ultra violet
WHO	World Health Organization
WRI	World Resources Institute

1 INTRODUCTION

A pesticide is a substance or mixture of substances used to kill a pest (EPA, 2008). The Food and Agriculture Organization (FAO) of the United Nations goes further in the definition of pesticides, including not only those substances for killing pests, but also those that control pests' behavior or physiology, and those that control the physiology of the crops during production or storage (FAO, 2008a). Pesticides have brought some benefits to agriculture; however, they have also brought health risks to those exposed during preparation and application of pesticide, and risks to the environment. Pesticide exposure has been associated with acute health effects in the form of poisonings and acute contact dermatitis (Penagos, 2002). Pesticides also cause chronic health problem such as respiratory problems, dermatologic conditions, cancer, neurologic deficits, depression, memory disorders, miscarriages, and birth defects (Daniels et al., 1997; O'Malley, 1997; Engel et al., 2000; Penagos, 2002; Arcury et al., 2003; Garcia, 2003; Kamel and Joppin, 2004; Firestone et al., 2005; Mancini et al., 2005). In occupational agricultural settings most of this exposure occurs through dermal exposure.

There are several methods to evaluate dermal exposure to pesticides (Fenske, 2005). The available quantitative methods require the presence of well-trained personnel in analytical techniques and expensive equipments for sampling analysis. However, in developing countries conditions, exposure assessment methods must be low cost and easy-to-use. Observational qualitative and semiquantitative methods have been proved to be an alternative to this (Aragón, 2005). Moreover, semiquantitative methods provide information on priorities for intervention. On the other hand, the level of exposure to pesticides is so high in developing countries, that exposure assessment should focus on developing strategies for controlling exposure rather than quantifying the exposure.

The main aim of this thesis was to develop an approach to assess dermal exposure to pesticides that fulfill the exposure assessment requirements of developing countries. The developed approach is based on the observation of determinants of dermal exposure and the use of a simple algorithm to rate them. The approach also proposes the use of the fluorescent tracer technique as an indicator of exposure to pesticides. These methods should be put together in order to identify relevant determinants of pesticide contamination of the skin (fluorescence images). If farmers can see their contamination and the assessors can relate the contamination to the determinants, then the proposed changes to farmers' work practices would not only reduce the exposure, but motivate farmers to maintain the changes. This work pretends to be a tool for those who work in occupational hygiene in developing countries to assess exposure to pesticide.

2 BACKGROUND

2.1 PESTICIDES IN DEVELOPING COUNTRIES

In 2002, the World pesticide consumption was 2.6 millions tons with a 38 billions USD market value (Gurler et al., 2005). Approximately, eighty five percent of this consumption has been used at agricultural sector. The trend in agriculture, in developing countries, is to use least expensive pesticides, which are usually the more toxic and environmentally persistent (Ecobichon, 2001). Many of these chemicals have been banned in the producing nations, but are freely available in the world market. In 1995, approximately 70,000-80,000 tons of these compounds were applied in developing and formerly socialist countries (WRI, 1996). By 2000, pesticide sales showed an increase of 2.8% in North America, 2% in Latin America, 3% in Japan, 10.5% in Asia-pacific region (Gurler et al., 2005). According to data from 2003-2004, the Latin American region pesticide sales increased 30% during this period, and are projected to increase from US$ 5.4 billion in 2004 to US$ 7.5 billion by 2009 (Brodesser et al., 2008). These projections reveal that pesticide consumption in Latin America would increase 15 fold.

Data from Central America are quite similar. Bravo and co-authors (2008) collected pesticide import data from Central America for the period 2000-2004. According to this, Central America imported a total of 163,917 tons of pesticides for this period; about 30,000 tons per year of 600 different pesticide active ingredients. The countries that imported the most were Costa Rica, Guatemala and Honduras, with 52,732, 51,254, and 29,968 tons, respectively. The three most imported pesticides were paraquat, methyl bromide and terbufos. However, when comparing consumption as the number of metric tons consumed per hectare, Costa Rica and Belize are the most intensive pesticide users in Latin America (WRI, 1996), applying 18.0 metric tons/hectare (MT/ha) and 17.4 MT/ha, respectively.

The most effective way of reducing the impact of pesticides is by reducing their use. Several methods have been suggested to minimize pesticide use and exposure, such as the Food and Agriculture Organization Code of Conduct (FAO, 2005) and the Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade (FAO/UNEP, 1998). In 1985, the FAO initiated a voluntary Code of Conduct, which established voluntary standards of conduct for all public and private entities engaged in, or associated with, the distribution and use of pesticides. In 1998, the Rotterdam Convention was implemented on a voluntary basis to help countries to avoid using pesticides that are recognized to be harmful to human health and the environment and highly toxic pesticides that can not be handled safely by small farmers in developing countries. However, the problems remain: national pesticide legislation is not widely enforced due to lack of technical expertise and resources (Sam et al., 2008); highly hazardous or sub-standard pesticide formulations are still widely sold; and end-users are often insufficiently trained and protected to ensure safe handling of pesticides (Brodesser et al., 2008). Furthermore, pesticide poisoning remains a public health concern, especially in developing countries (FAO, 2008b).

Several approaches have been used to estimate the incidence of acute pesticide poisoning in farmers and other agricultural workers worldwide, resulting in global regional, national, and local estimates (Litchfield, 2005). These methods have often been based on extrapolations from a small number of countries, and in case of epidemiological studies, rely on hospital and poison centre data, which captures mainly the most severe poisonings. Nevertheless, World Health Organization (WHO) estimated that in the period 1987-1988 occurred 1 million unintentional severe acute pesticide poisonings, and 220,000 deaths (WHO, 1990). The majority of the intoxications were attributed to the organophosphorous and carbamate ester insecticides (Leveridge, 1996; Yang et al., 1996).

In Central American countries (Belize, Guatemala, El Salvador, Honduras, Nicaragua, Costa Rica y Panama), the Pan American Health Organization (PAHO) established epidemiological systems (PAHO, 2002). Data from these systems were used for analysis of cases reported between 1992 and 2000 (Henao and Arbelaez, 2002). The incidence rate increased progressively from 6.3 to 19.5 per 100,000 inhabitants in this period. These figures included occupational, accidental and intentional cases. In 2000, a total of 6934 cases were recorded, 11% of which were fatal and 36% occupationally related. Again, these figures are an underestimation of the real situation. When researchers interview farmers and farmworkers directly, studies show that 90% or more of all poisoning cases may go unreported by the medical establishment. For instance, the Pan American Health Organization (PAHO, 2002) found that over 95% of the cases of acute pesticide poisoning went unreported in Nicaragua, Belize, and Guatemala. PAHO estimates about 3% of exposed agricultural workers suffer from an episode of acute pesticide poisoning annually—with a population of about 1.3 billion agricultural workers worldwide, that means that as many as thirty-nine million people may suffer from acute poisonings each year.

2.2 PESTICIDE EXPOSURE OF NICARAGUAN FARMERS

The use of pesticides in Nicaragua started in the 50’s with the so called “cotton boom”, which extended till the 80’s. Unfortunately, there are no published data on importations for that period. However, data for the period 1980-99 showed that importations increased during the 80’s and fell in the early 90’s, to rise back at the end of 90’s. According to Hruska and Corriols (2002), Nicaragua imported approximately 27 millions USD at the beginning of the 80’s, and reached the 58 millions USD by the end of the 80’s. Then, importations fell till 11 millions USD during the early 90’s and went back till 51 millions USD by the end of the 90’s. Changes in government pesticide policies explained the rise of the 80’s: incentives were created that favour the use of pesticides on state farms (Hruska, 1990). In the 90’s changes occurred in the government and the incentives were removed. This probably explains the drop in the use of pesticide in those years. The raising of the end of the 90’s may be explained by the return to intensive monocultives such as peanut production in the region previously dedicated to cotton production.

In Nicaragua, pesticide poisoning has been well documented (McConnell, 1988; Amador, 1993; Keifer et al., 1996a; Corriols, 2002; Murray et al., 2002; Henao and Arbelaez, 2002). PAHO (2002) estimated the number of farmers affected by poisoning every year is 5.4% of the farming population of Nicaragua. These data are comparable to those of other developing countries. For instance, Sri Lanka and Malaysia presented poisoning rates of about 7% (Jeyaratnam et al., 1987), and Ivory Cost, 8% (Ajayi, 2000). In 2004, 1312 cases of acute poisoning were reported yielding an intoxication rate of 23/100,000 (MINSA, 2004). Of these intoxications 38% were occupational. More than 1/3 occurred in the Northwestern region, and 37% of those were caused by organophosphorous pesticides, primarily chlorpyrifos and methamidophos. Furthermore, poisonings occurred most frequently among subsistence farmers and part-time pesticide applicators (Berroterán, 2001). Recent official data showed an increase in the poisoning rates in 2007 (MINSA, 2008a) compared with 2006 (MINSA, 2008b); the rates were from 20.8 to 23.1 poisonings per 100,000 inhabitants in that period. However, Corriols et al. (2001) estimated that 98% of pesticide poisoning in Nicaragua remained unreported by the official statistics.

Several epidemiological studies have been carried out to evaluate the effects of exposure to pesticides (McConnell et al., 1990; McConnell et al., 1992; McConnell et al., 1994; Keifer et al., 1996b; McConnell et al., 1999; Miranda, 2003) among different Nicaraguan populations. However, only a couple of studies have aimed to evaluate exposure to pesticides in Nicaragua (Dowling et al., 2005; Rodriguez et al., 2006). These studies have used biological monitoring to evaluate organophosphorous pesticide exposures. In all cases the sampling analysis was carried out in facilities in the United States. Dowling et al. (2005) assessed small-scale farmers' exposure to chlorpyrifos through urinary residues of the insecticide metabolite (3,5,6-Trichloro-2-pyridinol). Farmers presented 20-100 fold increase from the pre-application level. In another study on small farmers and banana plantation employees, exposure to chlorpyrifos and diazinon was measured through their metabolites: 3,5,6-Trichloro-2-pyridinol and 2-isopropoxy-4-methyl-pyrimidinol, respectively (Rodriguez et al., 2006). Most of the farmers (91 %) presented residues of chlorpyrifos and a 30-fold increase from the pre-application level. The diazinon metabolite was found in 79% of the studied workers. However, no differences were found between pre- and post- application concentration of the metabolite. Diazinon was sprayed by the banana plantation workers, who wore protective equipment during applications. An explanation to these differences may be found in the conditions for pesticide application, which differed between small farmers and banana plantation workers, being the conditions for small farmers the worst.

Nicaraguan small farmers usually do apply pesticide in the morning with a backpack sprayer (motorized or manual). The use of any other application technique such as tractor mounted boom sprayer is out of their economical possibilities. In some cases pesticide mixing occurred in the household kitchen (Rodriguez et al., 2006), though in most cases took place at the edge of the field to be treated (Dowling et al., 2005; Aragon et al., 2001). Applicators prepare mixes barehanded using small tin cans or plastic bottles (100-200 ml) to transfer the formulated pesticide into the tank of the backpack. The amount of formulation is the same independently of the volume of the tank, which usually is 10 l (motorized backpack) or 20 l (manual backpack). Pesticide spraying occurs under high-risk conditions: no personal protective equipment and leaking backpacks. Backpacks are repaired right in the field with no precautions. The crop extension ranges from 1 to 4 Manzana (1 Manzana = 0.7 Ha) and the work period ranges from 1 to 2.5 hours. Similar conditions have been reported in other developing countries (Polidoro et al., 2008; Ngowi et al., 2007)

2.3 PESTICIDE EXPOSURE ASSESSMENT METHODS

Recognition of the importance of skin exposure during pesticide application in agricultural settings has steadily increased over the last few decades (Fenske, 2005). Several methods to evaluate dermal exposure to pesticides are available and comprehensive reviews have been presented (Durham and Wolfe, 1962; Davis, 1980; Chester, 1993; van-Hemmen and Brouwer, 1995; Fenske, 2005). These methods can be grouped into three general categories: qualitative, quantitative and semiquantitative. Qualitative methods are usually based on observation of assumed determinants of dermal exposure, which are used as qualitative exposure proxies (yes/no; exposed/non-exposed).

Quantitative methods are based in sample techniques that can be grouped into four subcategories: surrogate skin techniques (recently called interception techniques), chemical removal techniques, visualization techniques (direct techniques), and biomonitoring. The interception techniques intercept the agent by the use of collection media placed at the skin surface (patch technique) or replacing work clothing (the whole body technique) during the sampling time (Soutar et al., 2000). In the patch method, the potential contamination is measured using a variable number of absorbent cloth or patches attached to defined areas of the body, inside and outside clothing. The patches act as the collection medium for the pesticide. The patches are removed after exposure and analyzed for pesticide content. The quantity of a pesticide on a patch of known area is related to the area of the body part. The area of the body part of concern is obtained from standard charts (EPA, 1987). It is assumed that the pesticide has been uniformly deposited over the body part. This assumption is maybe the main disadvantage of this method, as the extrapolation of the values given by the limit of quantification (LOQ) to the total body part may give a substantial under- or over-estimate of exposure. This limitation can be addressed in part by increasing the number of patches located on body parts predicted to receive significant exposure. The total potential dermal exposure is obtained summing up the individual body part exposure values. This is expressed in mg/h, mg/d or mg/kg of product handled or applied. Also, as mg/cm^2 of the skin.

The whole body technique was designed to overcome these limitations by sampling entire anatomical regions using a coverall (WHO, 1982; Abbott et al., 1987). Exposure of the head is assessed by incorporating a hood into the coverall or using a separate cotton hat. Any protective clothing and equipment recommended for the product under study are worn over the sampling clothing, thus enabling an evaluation of their protection. This technique relies in the assumption that the collection medium captures and retains chemicals in a similar way to that of skin, which has not been systematically tested yet. Thus, the accuracy of this technique remains an open question. Following the exposure, the coverall is sectioned into individual body parts, which are analyzed separately.

A variant of the whole body method is the normal clothing approach. This approach involves the use of clothing and underwear that represents what the workers would normally wear, as outer and inner dosimeters (Chester et al., 1990). For analytical considerations, it may be necessary to use non-coloured, white materials such as cotton or cotton/polyester mixtures. As in the standard whole body method, the clothing is sectioned into individual body parts and analysed separately to determine the regional distribution of total potential and actual dermal exposure. This method is particularly relevant for countries where the typical work clothing consists of a T-shirt, long-sleeved shirt, socks and long trousers and/or coveralls. An advantage of the normal clothing variant of the whole body method is that it can be used to estimate dermal exposure in combination with the use of biological monitoring to measure absorbed dose. The standard whole body method, alike the patch method, places sampling media between the pesticide and the clothing or skin (thus acting as a barrier and interfering with the process of skin contamination and percutaneous absorption); this method mimics the capture, retention and penetration properties of normal work clothing as closely as possible.

Removal techniques aim to sample the mass of contaminant remaining on the skin of a particular body area by removing the chemical through washing, wiping or tape-stripping (Brouwer et al., 2000; Nylander, 2000). Washing is mostly used for the hands and has demonstrated good reproducibility in laboratory studies (Fenske and Lu, 1994). However, it requires large volumes (about 250 ml per hand) of the solvent. Washing the hands with a solvent is considered by some to disrupt skin barrier function and enhance percutaneous absorption of the pesticide. The EPA (1987) claimed that there is little actual evidence for this, and recommended washing using the bag rinse method developed by Durham and Wolfe (1962). Skin wiping is carried out with a gauze-pad impregnated with a solvent, though there is no standard protocol on how to wipe and how many times. Both techniques, skin wiping and washing, shows a high degree of variability in recovery efficiency (Brouwer et al., 2000). Tape stripping consists of removing the stratum corneum on the contaminated skin with a piece of adhesive tape. The residues in the tape represent the amount of contaminant that has already been absorbed (Nylander, 2000).

Visualization technique corresponds to in situ detection of an agent or tracer at the skin surface. This is usually achieved by the addition of fluorescent tracer to the material being handled or processed and video imaging analysis (Cherrie et al., 2000; Fenske and Birnbaun, 1997). This technique allows the visualization of dermal exposure patterns and has proven to be useful in exploring dermal exposure mechanisms and mitigation strategies.

Because actual determination of the external dermal exposure is extremely labor intensive and costly, a series of models to estimate external dermal exposure have been developed for specific work scenarios. These semiquantitative methods combine identified or assumed determinants of exposure (or contamination) with an algorithm to rate these determinants. An example of such a method is the DREAM (DeRmal Exposure Assessment Method) (van Wendel de Joode et al., 2003). DREAM consists of an inventory and an evaluation part. Each inventory part comprises six modules: company, department, agent, job, task and exposure. The modules address general information and possible determinants of exposure. The evaluation part takes place at task level following an algorithm. DREAM has shown to be a robust method (van Wendel de Joode et al., 2005).

An inherent complication of all models for the estimation of external exposure is that there are several dermal exposure pathways: direct contact of the skin through splashes or handling of material, deposition onto the skin from aerosols or mists of the substance, contact with contaminated surfaces. Also, the penetration of the substance, following exposure, is influenced by the duration of the exposure, the frequency of exposure, the dermal area, the condition of the skin and the anatomical site. Biomonitoring of dermal exposure can provide solutions to overcome these limitations (Cocker et al., 2002). Biological monitoring is a method of evaluating the absorption of chemicals by measuring the chemical or its metabolites in body fluids, usually urine, blood or exhaled breath (Anwar, 1997). The measured substance is call biomarker. If a biomarker is related to a health effect or modification of normal biochemical indices, it is called an effect biomarker; when a biomarker is not related with a health effect is called an exposure biomarker. Analysis of body fluids and excreta, most commonly blood and urine, for the parent compound or its metabolites can provide both a qualitative and a quantitative measurement of absorbed dose for those pesticides considered suitable candidates for biological monitoring. However, to obtain quantitative data on the amount of pesticide absorbed by workers, it is necessary to understand the metabolism and pharmacokinetics of the compound in humans. Perhaps the most frequently used biomarker for assessing exposure to organophosphate pesticides has been the blood cholinesterase activity (Nutley and Cocker, 1993). However, recent studies have shown that only in cases of severe organophosphorous exposure depression of cholinesterase activity leaves no ambiguity (Cocker et al., 2002).

2.4 PESTICIDE EXPOSURE ASSESSMENT METHODS REQUIREMENTS FOR DEVELOPING COUNTRIES

The starting point in occupational health research should be the contextualization of research; research should go out of laboratories and confront reality. On the one hand, developing countries lack well trained (or trained at all) occupational health professionals, and the money to adopt quantitative expensive methods. On the other hand, the exposure conditions are totally different from those in developed countries. In addition, poor nutrition and health status, and climatic conditions, may modify health risks, thus making results from studies performed in developed countries not applicable. Therefore, in developing countries conditions, exposure assessment methods must be low cost, easy-to-use, and control driven rather than compliance driven.

The easiest way to evaluate exposure is to follow a checklist of previously identified determinants of exposure. However such a method requires of expert knowledge for interpretation. In developing countries conditions, the qualifications of those working in the line of occupational hygiene are pretty limited. In such conditions, an exposure assessment method should provide the technician or the hygienist with the algorithm for interpreting the results: how-to identify those workers at risk and the practices that are priorities to be changed.

Farmers' exposure to pesticides, while using backpack sprayers, mainly occurs through the dermal route (Machera et al., 2003). Consequently, exposure to pesticides in farmers using backpack sprayers 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.

3 AIMS

The overall aim of this thesis was to develop a semi-quantitative approach to assess dermal exposure to pesticides relevant for conditions in developing countries.

Specific aims:

- To assess dermal exposure to pesticides of Nicaraguan small farmers using a semi-quantitative method: a modification of Fenske's Visual Scoring System.
- To define exposure determinants during pesticides application among Nicaraguan small farmers through direct observations and analysis of video recordings.
- To develop an easy-to-use method to assess dermal exposure to pesticides among small farmers based on dermal exposure determinants.
- To evaluate the reliability of the proposed method, to assess dermal exposure to pesticides based on determinants of exposure.

4 METHODS

4.1 DESIGN AND DATA COLLECTION

The information for this thesis was collected in two phases. In Phase I (studies I-III), data collection occurred in the period June-October/1999. These data were collected within the frame of a larger project named “Assessment of Dermal Pesticide Exposure and Pesticide-Related Skin Lesions: Implication for Intervention”, which was carried out by the Occupational and Environmental Health Program of the National Autonomous University of Nicaragua (UNAN-León). We used these data to answer the first three specific objectives.

As for Phase II (study IV), data collection took place during the late rainy season of 2007 (September-December). This study is part of an ongoing program aimed to assess the level of pesticide exposure of subsistence farmers at the community “Los Zanjones”, 20 km North of the city of Leon. This community was the one with the highest pesticide use and highest rates of occupational poisonings in the Northwestern region of Nicaragua, according to registers of the Ministry of Health. Data from this study were used to answer specific objective 4.

In Phase I, subsistence farmers were asked to allow us observe them during pesticide applications. They were told to apply as usual. We observed the applications and looked for determinants of dermal exposure with help of a guideline. All applications were videotaped and the videotapes were used to confirm the identified determinants. Also, a fluorescence tracer (Tinopal® CBS-X) was added to the pesticide mix in order to assess dermal exposure using a visual scoring system (Fenske, 1988) and to assess the performance of the modifications to this scoring system (Aragon et al., 2005). The correlation between the identified determinants and the estimates obtained with the visual scoring system were used to identify the relevant determinants of dermal exposure to pesticide among these farmers. The list of relevant determinants was used to propose a semi-quantitative easy-to-use method to assess dermal exposure to pesticides in subsistence farmers. The reliability of the proposed method was assessed with the help of 10 industrial engineers who worked in the line of occupational hygiene for the Nicaraguan Ministry of Labor. These engineers applied the proposed method to 5 pesticide applications videotaped during Phase II.

Both, Phase I and Phase II, studies were approved by the Ethics Committee for Biomedical Research of National Autonomous University of Nicaragua (UNAN-León), León, Nicaragua.

4.2 PARTICIPANTS

4.2.1 Studies I-III

For Phase I, community leaders in villages close to the cities of León and Chinandega, in the Northwestern region of the country, were contacted in order to identify subsistence farmers who applied the commonly used organophosphate insecticides: chlorpyrifos and methamidophos. The farmers were invited to participate in a meeting explaining the aim of the study and the methods of exposure assessment to be used. All the participants in the meeting had opportunity to ask questions. After all questions were answered and the meeting participants accepted to take part in the study a written consent form was signed. The farmers were recruited in the order they were notifying us their decision to apply pesticide. A total of 32 subsistence farmers were included in the study.

4.2.2 Study IV

For Phase II, a new group of 15 subsistence farmers were recruited following the same strategy as in Phase I, i.e. with help of the community leader of "Los Zanjones", we contacted subsistence farmers who were planning to apply pesticides to their crops. Then, in a meeting, we explained to farmers the goals of the study and the methods to be used, until the last doubt was cleared. Finally, those who accepted to participate in the study were asked to sign a written consent.

4.3 EXPOSURE ASSESSMENT

4.3.1 Study I

At this study we had to adapt the visual scoring system of Fenske (1988) to Nicaraguan conditions, and to assess the performance of the modified version. Thus, we used the fluorescent tracer and the total visual score, applied our modifications to the visual scoring system an assessed the performance of the modifications by comparing visual score estimates with the residues of pesticides in the skin with different fluorescent intensity. The methods used in the assessment are described ahead.

4.3.1.1 The fluorescent tracer and the Total Visual Score

A small amount (260 mg/l) of a whitening agent (Tinopal CBS-X®) was added as a fluorescent tracer to the pesticide dilution to be applied. Farmers applied pesticides as usual and were observed before and after application in a darkened room using a UV lamp (UVP® model UVSL-26P; 365 nm long wave). The pattern of fluorescent images on the skin of the farmer after application was videotaped using a camcorder (Hitachi® VMH-640A Hi8).

Each body part was evaluated using a matrix (Fenske, 1988) where the ordinate represented the exposed area and the abscissa exposure intensity. The exposed area (extent) was ranked from 1 to 5 (five ranges of 20%) and intensity from 0 to 5 (none to high). The product of these two ranks results in a score for the image ranging from 0 to 25. The total visual score is the sum of the scores of all body areas, and values may range from 0 to 775.

4.3.1.2 The modified visual scoring system

We modified the two components of the original system: the extent, by weighting the size of exposed body parts according to total body surface, and intensity, by establishing criteria for reading the fluorescence images. These modifications resulted in body segment scores (BSS) for specific body parts as well as two summary measures: the 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. In Table, 1 we present a summary of the modifications made to the original method.

Table 1. Modifications made to the visual scoring system of Fenske.

Original	Modification
Computer equipped dark room	Foldaway dark room
Large fixed UV lights for illumination	Portable UV lamp
Photographs of the fluorescence images	Videotaped images
7 body segments (face and hands; 9% total body surface)	31 body segments (91% total body surface, excluding buttocks and genitalia)
No scoring of area without fluorescence	Area without fluorescence scored 0
Scores for extent are independent of the size of the body part	Body segment scores weighted by size
Reading of intensity with no guidelines	Guidelines for reading of intensity based on deposition patterns

4.3.1.3 Skin wiping according to fluorescent intensities

Skin wipes were used to remove the residues of pesticide from skin areas with different fluorescence intensity. The area was wiped with 8.5 x 5 cm single gauze impregnated with 2 ml isopropanol 10%. The gauze was put into a vial and stored in a cooler for transportation to the laboratory. The wiped area was copied into a transparent plastic foil using a waterproof pen and the copy used to define the surface area in cm^2. The gauzes were analyzed for the two studied pesticides: chlorpyrifos and methamidophos, using capillary gas chromatography with electron capture detector and nitrogen-phosphorus detector, respectively. This procedure was performed for 24 farmers ending up with 127 samples.

4.3.2 Study II

At this study we used an observation guideline to identify determinants of dermal exposure to pesticides. We also reviewed videotaped pesticide applications to verify and confirm observed determinants. The observed determinants were assessed for correlation with the total visual score estimates obtained in the previous study. Thus we identified the relevant determinants of dermal exposure to pesticides in this group of farmers. The assessment methods used in this study are described below; because the total visual score was described in methods for study I, we do not describe it for study II.

4.3.2.1 Observation guideline

A list of the different activities and potential exposure events during pesticide application was established based on previous field observations, and used as a guideline to collect information on potential determinants of dermal exposure. Major operations such as mixing, loading and spraying were broken down into smaller components. All activities were included, from the moment a farmer starts preparations for the application until the end of the work operation, when equipment and pesticide leftovers are stored. Data on clothing, personal protective equipment and climatic conditions were also considered. Thus, a list of factors entailing potential dermal exposure was used to design a preliminary form to guide the field observation. This form was tested during the pilot phase of the study and some exposure events that had not been anticipated were added to the observation guide.

4.3.2.2 Video recording

In order to confirm and complement the data collected directly in the field with the use of the observation guideline, the pesticide applications were also videotaped. When the farmer decided to apply more than five tank loads, we filmed the application intermittently for up to an hour and a half, taking care to include all relevant activities and potential exposure events.

4.3.3 Study III

Those relevant determinants, identified in study II, were used in the development of a method to assess dermal exposure to pesticides in conditions such as in Nicaragua. Also, a performance assessment was carried out by comparing the new estimates with those obtained with the total visual score. Below, we describe the proposed method. The total visual score was described in study I.

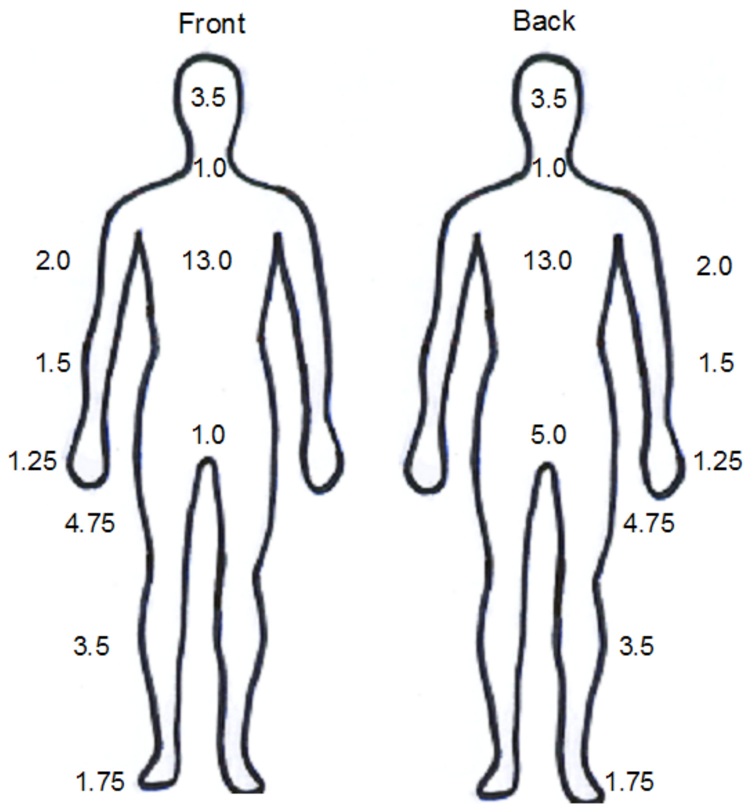

Figure 1. Guideline to estimate the area (%) of the body surface affected for each determinant; for upper and lower extremities the figures here represent only one side of the body.

4.3.3.1 Determinants of dermal Exposure Ranking Method (DERM)

DERM is a combination checklist and expert rating assessment. Relevant determinants of dermal exposure are listed in a form and assessed by observation using a simple algorithm. The algorithm is based in two factors: the type of Transport process (T value), and the Area of body exposed (A value). Then, the estimates of each determinant are summed up, resulting in the assessment of potential dermal exposure. In addition, the type of clothing (C value), worn by the farmer during the pesticide application, is included as a protection factor. The product of this protection factor and the sum of the determinant estimates provides an estimate of the actual dermal exposure. A scheme of the algorithm is presented in fig 2.

The type of transport process (T value) is evaluated in terms of emission, deposition, and transfer of the pesticide to the skin or clothing of the farmer (Schneider et al., 1999). The scores are defined by the following assumptions: transfer processes lead to low exposure, deposition processes to a medium exposure, and emission processes to high exposure. A score of one or three is assigned to low exposure (transfer process), four to medium exposure (deposition), and five to high exposure (emission processes) (Table 2).

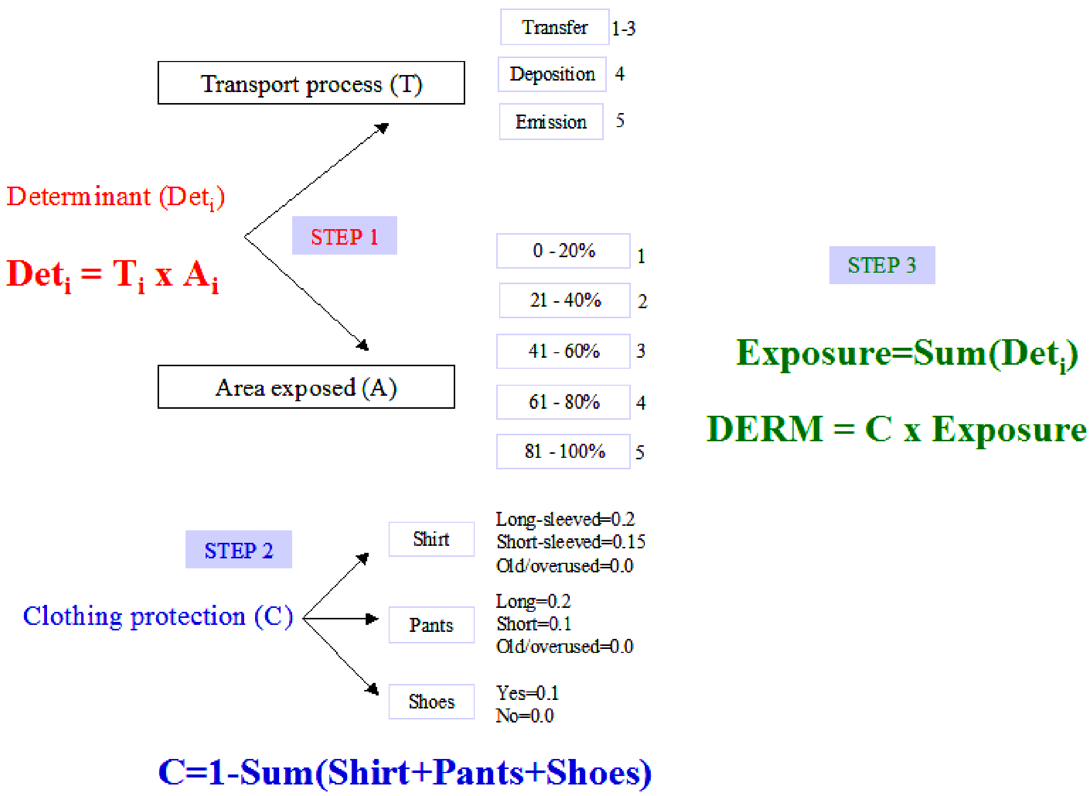

Figure 2. Scheme of the DERM algorithm. Step 1: each determinant is assessed by factors T and A; Step 2: the clothing worn by the farmer is assessed; and Step3: estimation of the potential dermal exposure and DERM. See further description in the text.

The area (A value) of the body surface that gets contaminated by a particular determinant is ranked from 1 to 5, representing categories with ranges of 20% of the total body surface as follows: 0-20%; 21-40%, 41-60% and so on. 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 (Figure 1).

Clothing protection factor (C value) is defined as the complement of the reduction in the exposure level (1 - exposure reduction) that occurred with the clothing worn. This factor took into account the different types of clothing worn by farmers (Table 2).

Table 2. Scores for categories of factors of Transport and Area of body surface, and the scores to assess the protection provided by Clothing as used in DERM method.

Factor	Category	Sub-category / 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
Piece of clothing			Exposure reduction
Shirt	Long-sleeved		0.20
	Short-sleeved		0.15
	Old/overused/torn		0
Pants	Long		0.20
	Short		0.10
	Old/overused/torn		0
Shoes	Yes		0.10
	No		0

4.3.4 Study IV

In order to assess the reliability of the proposed DERM method, ten raters were trained in the use of DERM and invited to apply it to 5 videotaped pesticide applications. The raters were industrial engineers working as occupational hygienists at the Nicaraguan Ministry of Labor. They had different level of experience in exposure assessment (one year or less, and six or more years). The training session lasted 2 hours and included a theoretical part and practice with two videotaped applications that were not part of those used for this study. The readings of the 5 videotapes were carried out in two sessions and the scores annotated in a form designed for that, as presented in the appendix on paper IV.

4.4 DATA ANALYSES

4.4.1 Study I

Means, standard deviation and ranges for contaminated body area, body segment scores, total visual scores, and amount of pesticide residues in wipes by intensity ($\mu g/cm^2$), were calculated. The body segments most prone to contamination were identified. Also, Spearman correlation coefficients were calculated for pesticide residues and the six categories of intensity scores (0-5). Means for pesticide residues in the wiped areas were calculated, and adjusted for concentration of pesticide in the applied mix.

4.4.2 Study II

A multistep reduction strategy was used to reduce about 110 potential determinants into 27. Descriptive measurements for these determinants were estimated. The 27 determinants were then classified into 5 groups: worksite, spray equipment, clothing, working practices, and hygiene practices. Multivariate analyses were conducted within groups with the total visual score as the dependent variable. Those determinants within the groups with a p-value < 0.25 were entered into a cross-group multivariate model. The R^2 coefficient was used to describe the variability in the total visual score explained by the model.

4.4.3 Study III

Descriptive measurements of the DERM estimates were estimated. The farmers with the highest estimates were identified and also the determinants that most contributed to these estimates. DERM estimates were compared to the total visual score and contaminated body area estimates by means of Spearman correlation coefficients and by visual contrast of the rankings in order to assess the performance of DERM method.

4.4.4 Study IV

DERM estimates on each farmer were described, using the median and range, by the total of raters and by group according to their years of experience. Also, DERM estimates were plotted by farmer for the 10 raters in order to identify trends of raters' estimates. The inter-rater agreement and the internal consistency were assessed by the inter rater correlation coefficient (two way random model) and the Cronbach's alpha. Because the scores for most determinants depended on transport (T) processes and the area (A) of the body surface, the percentage agreement of these scores were evaluated as the percentage of the percentages of the raters having identical scores on each factor for a specific determinant.

5 RESULTS

5.1 STUDY I

The visual scoring system relies on the assessment of extent and intensity of fluorescent images on each body segment of the exposed farmer. Hence, the major modifications were aimed to provide guidelines to standardize the qualitative assessment of those parameters. According to the guidelines for the extent of the fluorescent images, the most common fluorescent depositions were those caused by contact with contaminated surfaces (smear), though splashes and mist, and combination of patterns were also observed. The body segments that more frequently showed fluorescence contamination were the front and back of the hands (87% of farmers), the front of the left forearm (75%), and the back of the trunk (75%). In contrast, the less frequently were the front of the right upper arm (19%) and the back of the right thigh. The highest body segment score (BSS) was estimated for the back (mean: 28.6; range: 2.6-65.0) and the highest total visual score represented 65% of the maximum possible.

In general, intensity scores correlated well with pesticide residues in the wiped areas (r=0.63). 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 (Table 3).

Table 3. Residues of chlorpyrifos (n=54) and methamidophos (n=73) according to intensity gradient of fluorescent tracer on skin.

Intensity	Mean (SD) (μg/cm^2)	Range
Chlorpyrifos		
Clean (n=13)	0.04 (0.07)	<LOQ[*]-0.27
Low and moderate (n=27)	0.59 (0.93)	<LOQ-3.97
High (n=14)	4.60 (6.60)	0.01-23.4
Methamidophos		
Clean (n=16)	0.01 (0.02)	<LOQ-0.06
Low and moderate (n=38)	0.17 (0.35)	<LOQ-1.92
High (n=19)	1.09 (1.49)	0.02-4.88

[*] LOQ – Level of Quantification: chlorpyrifos=0.04 μg; methamidophos=0.1μg.

5.2 STUDY II

The twenty seven relevant determinants of dermal exposure to pesticide were grouped into 5 categories and summarized in Table 4. The univariate analysis showed that the determinants that were significantly and positively correlated with the modified total visual score were worksite (temperature, wet or slightly muddy terrain), spraying equipment (type of backpack sprayer), and working practices related determinants (volume of sprayed dilution, spraying with nozzle directed in front, splashing on the feet, and gross contamination of the hands). On the other hands, only the "having a helper" determinant showed to significantly reduce the exposure. In the within group analyses, work practices, spray equipment and worksite related determinants explained 52, 33 and 25% of the exposure variability, respectively. Clothing and hygiene practices were weaker determinants and did not always reduce the exposure. In the across group multivariate regressions, sprayed surface, spraying on a wet or slightly muddy terrain, using a manual backpack sprayer, gross contamination of the hands emerged as the strongest determinant for increasing the total visual score; wearing long pants emerged as the only preventive factor. The variability explained for such a model was 69%.

5.3 STUDY III

The average DERM estimates was 26.8 (SD=11.1) with a range of 9.8-57.0. Farmers 4, 17, 2 and 1 presented the highest potential dermal exposure (no clothing protection factor included). After applying the clothing protection factor, the farmers with the highest DERM estimates, were 4, 2, and 6. The determinants that most affected the exposure of these farmers were those related with the position or height of the spraying nozzle: spraying with nozzle in front, nozzle height, spraying against the wind, and the height of the crop; and using a leaking backpack sprayer.

Spearman correlation coefficients were calculated for DERM-TVS and DERM-CBA, showing good correlation between the methods ($\rho=0.69$ $p<0.01$; $\rho=0.67$ $p<0.01$, respectively). A close examination of the ranking of DERM, TVS and CBA, showed that 75% of the applications (24 out of 32) were ranked within the range of 1-5 ranks of difference. However, in 16% (5 out of 32) the exposures were ranked differently (>10 ranks), i.e. applications ranked as representing high exposure with DERM (3 out of 5) were ranked as low exposure with TVS or CBA and vice versa (2 out of 5).

5.4 STUDY IV

The DERM scores of farmers ranged between 9.9 and 40.7, with a median of 20.9. The less experienced raters were tougher in their evaluations than the most experienced. The inter-rater agreement was relatively good (ICC=0.67; 95% Confidence Interval = 0.37-0.9). However, it was better within the least experienced raters. The internal consistency within the 10 raters was excellent (Cronbach's alpha = 0.99) with no important differences between groups.

Raters did have excellent agreement assigning scores to transport processes. However, one rater misclassified splashes as deposition instead of emission. The agreement on assessing the area factor was good except for those determinants that affected different body parts at the same time such as height of the crop or the nozzle and the direction of the spraying either in front or against the wind. The assessment of the clothing protection factor was exactly the same for all raters on each farmer.

Table 4. Results of univariate analyses of potential pesticide exposure determinants with the Total Visual Score as the dependent variable. Subsistence farmers, León, Nicaragua, n=32.

Group	Factor	Mean (range)	Freq	β (95%CI)	p
Worksite	Temperature (ºC)	27 (21–32)		13.2 (0.1; 26.2)	0.05
	Sprayed surface (Ha)	1.25 (0.35–4.20)		11.6 (-10.9; 34.1)	0.30
	Height of the crop (cm)	57 (10-175)		-0.2 (-0.9; 0.5)	0.57
	Dew on plants		22	14.8 (-55.2; 84.9)	0.67
	Slightly sloping terrain		8	-11.7 (-86.8; 63.4)	0.75
	Wet or slightly muddy terrain		10	66.5 (0.7; 132.3)	0.05
Spraying Equipment	Hand-pressurized backpack sprayer (vs. a motor-pressurized sprayer)		13	102.8 (48.7; 157.0)	0.00
	Leaking backpack		19	36.7 (-28.1; 101.6)	0.26
Clothing	Wearing cap/head gear		27	40.7 (-47.7; 129.2)	0.35
	Wearing long-sleeved shirt		15	-21.0 (-85.8; 43.8)	0.51
	Wearing an old/overused shirt		19	22.8 (-42.9; 88.6)	0.48
	Shirt partially uncovering chest or abdomen		27	29.9 (-12.5; 72.2)	0.16
	Wearing long pants		24	-39.3 (-113.1; 34.5)	0.28
	Wearing shoes		5	-25.3 (-114.6; 63.9)	0.56
Work practices	Volume of sprayed dilution (l)	51 (10 –120)		1.6 (0.5; 2.6)	0.00
	Nozzle height (cm)	80 (40-160)		-0.5 (-1.7; 0.6)	0.35
	Nozzle – applicator body distance (cm)	35 (20-180)		0.5 (-1.3; 2.3)	0.57
	Spraying with nozzle directed in front		12	88.2 (29.5; 146.9)	0.00
	Spraying against wind		20	42.8 (-22.5; 108.2)	0.19
	Having a helper		16	-79.8 (-137.8;-21.8)	0.00
	Splashing/spilling dilution over the pump		24	22.6 (-52.2; 97.3)	0.54
	Splashing hands		23	21.2 (-50.8; 93.2)	0.55
	Splashing on the feet		15	79.7 (21.6; 137.8)	0.00
	Gross contamination of the hands by blocking a hose leakage, repairing nozzle or entering hand into tank		15	75.5 (16.6; 134.4)	0.01
Hygiene practices	Rinsing of hands		4	41.7 (-55.6; 138.9)	0.38
	Wiping sweat off the face with a piece of cloth or shirt		5	69.5 (-16.4; 155.4)	0.10
	Sealing tank lid with a piece of cloth		7	-47.1 (-123.9; 29.7)	0.22

6 DISCUSSION

This thesis intended to propose an approach to assess exposure to pesticides under conditions of developing countries. To reach this goal we based our work on the assumption that exposure in developing countries is so high that exposure assessment must focus on control rather than quantification of exposure. Moreover, the methods to be used, within this approach, should be of low cost and easy to use. Therefore, we adapted the visual scoring system to assess fluorescent images (Fenske, 1988) and used this to identify relevant determinants of dermal exposure to pesticide in Nicaraguan subsistence farmers. Subsequently, we used these determinants to develop an easy to use and low cost method, called DERM, which could complement the fluorescent tracer in the search for strategies for interventions to control exposure to pesticides among these farmers. Finally, the reliability and performance of the DERM method was assessed. Below, a brief discussion of the main findings is presented.

6.1 DATA COLLECTION

6.1.1 The participants selection

This study was carried out in two phases: one to develop the method and another to assess the validity of the method. The criteria for selection of the participants were being a subsistence farmer of the Northwestern region, which is the region where the highest pesticide poisoning rates has been observed. Thirty two pesticide applications from 12 different communities were observed in Phase I. Phase II is part of a larger study to assess the reliability and validity of DERM. Here the results of the reliability study are presented. The Phase II consisted of 15 pesticide observations in the community with the highest pesticide poisoning rate in the northwestern region of Nicaragua in 2007. The number of participants, in both Phases, seemed to be reasonable for assessing correlations between determinants and the total visual score, when considering the time needed to perform the observations. In addition, the multistep reduction strategy provided with the opportunity to work with a few determinants at the same time.

6.1.2 The methods selection

To choose the methods to be used in the study, a literature review of them was carried out. Machera et al. (2003) showed that dermal exposure to pesticides is more relevant than respiratory exposure in applicators using low pressure backpack sprayer. Also, dermal exposure has been shown to be relevant for those pesticides with high lipo-solubility (van Hemmen, 1993), such as chlorpyrifos and methamidophos, the two most frequently used pesticides in Nicaragua. Therefore, in this study, to focus on dermal exposure was considered a reasonable exposure assessment strategy.

Evaluating dermal exposure is a complex task. Chemical-skin interaction results in large within- and between-exposed groups variability (Kromhout et al., 2004). Marquart and coworkers (2001) pointed out the need for developing simple tools to evaluate and control the risks of dermal exposure in small- and medium-sized workplaces. Large projects, such as RISKOFDERM, have been working on standardizing terminology and developing a simple model to evaluate dermal exposure

(Schneider et al., 1999; van Hemmen et al., 2003). However, still little is know about the applicability of these methods under developing countries conditions. The methods to be used in countries like Nicaragua need to be of low cost and simple to use.

Three methods were selected to assess dermal exposure: field observations and videotape analysis (qualitative methods), the fluorescent tracer technique with a visual scoring system (semiquantitative method), and skin wiping (quantitative method). The latter was used to assess the performance of the visual scoring system. A pilot study was carried out to pre-test the selected methods and improvements were made concerning data collection and ethical aspects. In case of observation and videotaping, light modifications were made to the guideline and the way for videotaping. The guideline form was restructured in order to reflect the application cycle (mixing and spraying of pesticide) and to simplify data collection. The videotaping was organized in order to include only the activities related to pesticide handling, spraying practices and fixing of the spraying equipment. Also, because of the repetitiveness of activities, when more than three cycles were expected, according to farmer's planning, the remaining cycles were filmed randomly. Skin wiping and fluorescent observations were made in alternating short periods so the farmer does not have to be inside the dark room for a long time (the temperature inside the dark room was over 40 ºC). First we observed the upper part of the body, and then we wiped hands, the lower part of the body was observed after that, and finally, skin areas with different fluorescent intensities were wiped. Ethical improvements included the provision of eye protection against UV illumination.

The guideline was easy to follow and the observation, in general, had excellent acceptance by participants. The videotapes provided a record of work events and details that otherwise were missed. The analysis of videotapes increase the ability to accurately identify and rank exposed workers. The videotape was designed to enhance general understanding of the application process rather than the farmers' behaviours and how they related to exposure levels. For example, because the farmers were very mobile during applications, there were instances when the camera did not follow them and they were hidden from our view. It is not clear to what extent our evaluations were biased, or in which direction they were biased, by these limitations. The ability to observe and properly rate the relationship between behavior and exposure levels could be improved in future studies by ensuring that during videotaping the subject is followed the whole work period, especially when mobile, and that the recording time of the video includes the entire exposure monitoring period. This research suggests that the use of video exposure might help to improve the ability of researchers to identify exposure determinants and correlate behavior and exposure levels.

6.2 THE VISUAL SCORING SYSTEM MODIFICATION

In paper I, we presented the changes made to the visual scoring system of Fenske (1988). The visual scoring system consists of two basic components: the extent of the fluorescence image and the intensity of that image. The original system evaluated only the uncovered body parts, which is relative while wearing normal old clothing to apply pesticides. Thus, we first extended the system to the total body surface. Further, the extent of the exposure was corrected by developing a body segment score (BSS), which in turn was combined to obtain the contaminated body area (CBA) index. Aragón et al.

(2005) evaluated the performance of the BSS, and find a good correlation between the scores for the hands and the amount of residues removed by wiping. Therefore, the body segment scores may be used to identify the body parts with the highest contamination.

The evaluation of the intensity of the fluorescence images by observation seemed to be subjective. Therefore, a guideline was proposed to assess the intensity. The performance of this guideline was tested against the wiping of skin with different intensity levels, resulting in a satisfactory performance. Partial misclassification occurred both while assessing low contaminated areas, which resulted with non detectable amount of pesticides, and conversely, while assessing non-detected intensity areas (clean areas), which resulted with pesticide residues. Nevertheless, the guideline permitted identifies common patterns on the images that indicated potential exposure pathways. Moreover, the fluorescence technique allowed the farmers to observe by themselves their potential body contamination with the pesticide. This motivated reactions of concern among the farmers; they usually ran to shower after the observation of the images on their bodies.

This dermal exposure assessment method adapts the fluorescent tracer and the visual scoring system to provide a low cost instrument capable of accurate and reproducible measurements, rapid data collection and analysis, and analysis by body part.

6.3 THE DETERMINANTS OF DERMAL EXPOSURE

Knowledge and understanding of the determinants of exposure are relevant for the design of efficient control strategies. Moreover, workers needing intervention may be identified on the base of determinants of exposure. Dermal route is generally the predominant route of entry for occupational pesticide exposure (van Hemmen, 1993; Machera et al., 2003). For some pesticides, however, inhalation exposure might also be important when pesticides are applied as mists or fogs, as well as in the cases of volatile compounds. Though the pesticides were applied as mists, they were sprayed with low pressure backpack sprayers. According to Machera et al (2003), dermal exposure was 7-fold higher than inhalation exposure in applications with low pressure backpack sprayers. Also, the pesticides applied, chlorpyrifos and methamidophos, by the farmers in these studies have low volatility. Thus, the identification of relevant determinants of dermal exposure to pesticide must be a necessary part of any exposure assessment to develop control strategies among the studied farmers.

We identified the most relevant determinants of dermal exposure among subsistence farmers by correlating those factors potentially increasing/reducing dermal exposure with the total visual score. Determinants related to work practices, spraying equipment and workplace conditions resulted to explain most of the variability in exposure as assessed by the total visual score. Clothing and hygiene practices related determinants were not such protective as expected. However wearing shoes (any type), long pants and long-sleeved shirts reduced the exposure.

Determinants of dermal exposure may be grouped by the body part they mainly affect, and thus, to predict the potentially contaminated body areas. According to the within group models, the work practices increasing the contamination were spraying with nozzle directed in front, splashing on the feet, and gross contamination of the hands. The two formers may be related to lower extremities contamination and the latter to the hands. The spraying equipment related determinants that increased the contamination were the type of backpack sprayer ad using a leaking backpack. Both may be easily related to back contamination. Thus, most of the identified determinants indicate exposure of the legs and feet, hands, and back. In fact, the farmers presented the highest visual score on hands, feet, back and the front of the legs.

6.4 THE DERM METHOD AND ITS RELIABILITY

The DERM 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. According to Marquart et al. (2003) such a method should be based on the job specific determinants rather than on rough categorization of tasks or unclear situations. Thus, DERM was based on the determinants identified on paper II of this thesis. However, this list of determinants may be modified in the future as other relevant determinants appear. The algorithm to assess the determinants was based on the dermal conceptual model (Schneider et al., 1999) and as such may be used on other previously identified determinants of dermal exposure to pesticide.

The reliability of the DERM was assessed with the help of ten engineers, who worked for the Nicaraguan Ministry of Labor, with low (<= 1 year) and high (>= 6 years) experience. We found that DERM had a good inter-rater agreement (ICC = 0.67; 95%CI = 0.37-0.95) and high between-rater consistency for ranking farmer's exposure (Cronbach's alpha = 0.95). However, the occupational hygienists with less experience showed a better inter-rater agreement. A possible explanation of this result is that raters with more years of experience assessed the determinants with excessive confidence in their skills and consequently their assessment was less attentive.

The raters coincided on those determinants with the highest scores among these farmers, which can be grouped as 1) the "volume of dilution (mix) sprayed"; 2) determinants related with the position of the nozzle/lancet (spraying with the nozzle directed in front, nozzle height, and spraying against the wind); 3) determinants related with the hands exposure (gross contamination of the hands and splashes on the hands). These determinants imply contamination of the legs, feet and hands; the same body areas identified with the fluorescent tracer.

Reliability is a necessary part of the validity process (Armstrong et al., 1994), but not sufficient. Thus, an attempt to assess the performance of DERM was done by comparing DERM estimates to those obtained with the total visual score. The DERM algorithm was applied to 16 out of the 27 determinants identified in Paper II. The remaining 11 determinants were excluded because their influence on dermal exposure was of complex nature in terms of transport processes and the area of body surface exposed. More studies need to be done to understand how, for instance, temperature and other worksite related determinants influence dermal exposure. A multiple linear regression model constructed on the basis of the 16 determinants selected explained 73% of the total visual score ($r^2 = 0.73$; $p = 0.02$), in contrast to 69% explained in the final model presented in Paper II. However, it has to be mentioned that not all 16 determinants presented statistically significant determination (β-coefficient). The intention of this exercise was to test the performance of DERM algorithm on a group of dermal exposure determinants in order to see whether the algorithm may provide information on the highest exposed farmers and the determinants that most influenced the estimates. The results obtained in this exercise showed that DERM promises to be a easy to use tool to assess dermal exposure.

The DERM and the total visual score showed a good level of agreement (DERM-TVS $\rho=0.69$, $p<0.00$). Nevertheless, a close examination of the scores showed that some factors may lead to opposite results. For instance, in three pesticide applications we obtained low total visual score estimates in opposition to high DERM estimates. Wearing loose on the body clothing affected the amount of fluorescent tracer that reached the skin. This determinant was not considered in the study, though it could be observed in the videotapes of the applications.

6.5 CONCLUSIONS

- Semiquantitative methods allow easy and low cost evaluation of exposure to pesticide.
- The fluorescent tracer technique allows identification of contamination pattern and some clues on the work practices with great impact on dermal exposure.
- The multistep reduction strategy based on regression analysis can be used to generate data for developing job specific questionnaires.
- Assessment of determinants of exposure with the DERM algorithm is reliable and can be used to identify highly exposed farmers and relevant determinants of exposure.
- Combination of fluorescent tracer and DERM might be of help in interventions programs to control exposure to pesticides; relevant determinants of exposure may be identified with DERM and the fluorescent tracer may be used to demonstrate the contamination.

6.6 FURTHER RESEARCH

Suggestions for future research:

- To assess the validity of DERM against a quantitative method as a tool to assess dermal exposure to pesticide.
- Test the combination of fluorescent tracer and DERM methods in intervention studies focusing on changing work practices to contribute to reduce exposure to pesticides.
- Evaluation of the level of exposure of those body parts most frequently contaminated (back, hands, feet and legs).
- Evaluation of exposure to pesticide of those who help farmers to apply the pesticides (spouses, children, partners).
- Health effects from chronic exposure to pesticides.
- Studies on para-occupational exposure to pesticide (take home pesticide).

7 ACKNOWLEDGEMENTS

The simplest words for this section could be *"Dear friends, thanks for the role you have played in my professional life and for all you have done to make this dream a reality"*. However, in spite of the small space, I want to say a word to those, who contributed to the dream. I am deeply certain that they deserve it. In the case I forget someone, I want to use this moment to apologize and present my gratitude to them.

First, I want to say thank you to my colleague in biophysics and friend, Edmundo Torres. Edmundo invited me to do research in his biomonitoring laboratory, so I could keep some research abilities while a job opportunity could be found. Edmundo introduced me to Aurora Aragon, who in turn invited me to become an occupational hygienist. Aurora, I hope you had in mind this moment when you involved me in this. My eternal gratitude to both of you.

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