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# Dermal exposure to pesticides in Nicaragua
# A qualitative and quantitative approach

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*To my parents Luis and Aurora*
*my seven sisters*
*Lorena, Ivette, Leonor, Magda, Sheyla, Patricia and Maria Cecilia*
*and my husband Andres*

*"In Central America, an array of structures creates a context in which unsafe pesticide practices are at times the sensible, if not the only possible, line of action for many small farmers and wageworkers".*

*Murray & Taylor (2001)*

"Ya estamos cerca de León, el territorio liberado.
Una intensa luz rojo-anaranjada, como la brasa de un puro:
Corinto:
la potente iluminación de los muelles rielando en el mar.
Y ahora ya la playa de Poneloya, y el avión entrando
a tierra,
el cordón de espuma de la costa radiante bajo la luna.
El avión bajando. Un olor a insecticida.
Y me dice Sergio: 'El olor de Nicaragua!'"

*Ernesto Cardenal (poeta)*

# Abstract

**Background:** Pesticide use continues to be a serious public health problem in developing countries, despite decades of "safe pesticide use" strategies. In Nicaragua, organophosphate insecticides, in particular chlorpyrifos and methamidophos are responsible for about half of the acute pesticide poisonings. Contamination of the skin occurs frequently in the occupational setting. There is extensive research to improve methods to assess dermal exposure. The applicability and feasibility of such methods in developing countries is uncertain.

**Aim:** This thesis aims at increasing the understanding of risk factors underlying exposure, evaluating dermal exposure among Nicaraguan subsistence farmers, and proposing more suitable methods for developing country conditions.

**Methods:** A group of 29 subsistence farmers were interviewed in four focus groups and their responses were analyzed using grounded theory. Field data for semi-quantitative and quantitative exposure measurements of 31 farmers were collected during 33 pesticide applications, using observation, supplementary video recording, a fluorescent tracer, and skin wiping. A visual scoring system developed in the US was modified into a Nicaraguan Visual Scoring System suitable for developing country conditions. Pesticides were traced during application. Skin fluorescence was videotaped in a foldaway darkened room which was later measured through Body Segment Scores (BSS), Contaminated Body Area (CBA) and Total Visual Score (TVS). TVS was used as a criterion indicator for the identification of main exposure determinants by observation. Univariate and multivariate analyses were performed. Hundred and ten potential exposure determinants were reduced to 27 variables grouped as worksite, spray equipment, work practices, clothing, and hygiene practices. Reliability of the visual score was tested with intraclass correlation coefficients, in a sub-sample of five farmers evaluated by five raters. Observations of hand exposure events (direct and indirect contacts) were summarized into a Concentrate Contamination Index (CCI) and a Solution Contamination Index (SCI). Chemical residues were quantified for the hands and selected body parts according to fluorescent intensities. Spearman rank correlation coefficients were computed to compare the observational indices (CCI+SCI), fluorescent visual scores and quantitative residues.

**Results:** Reasons for unsafe practices were connected with poverty, inadequacy of personal protective equipment, climatic factors, and limited knowledge influenced by beliefs and traditions. Farmers felt affection towards their traditional crops and this relationship seemed to have strong meanings for pest removal and pesticide use, contributing to dangerous work practices. The observed fluorescent images on the skin of farmers reflected work practices and contamination mechanisms and pathways. Novel determinants included spraying on a muddy terrain, dew on plants, sealing of tank lids with a cloth, and wiping sweat from the face. The Visual Scoring System was highly consistent (Cronbach alpha = 0.96) and reasonably reliable (0.75; 95% CI: 0.62-0.83), with scoring of extent being more reliable than scoring of intensity. The highest CBA was 66% and the farmer with the highest TVS scored 60% of the maximum possible. Hands were most frequently contaminated and the back had the highest BSS. Hand contact was most frequently indirect, by touching contaminated surfaces. All farmers had quantifiable pesticide residues on their hands. Spearman correlation coefficients between the observational contamination scores, fluorescent visual scores and residues in relation to the hands ranged from 0.65 to 0.74 for chlorpyrifos and 0.62 to 0.87 for methamidophos. Differences in scores could be explained by limitations of the different methods.

**Conclusions:** Poverty and cultural factors contribute to pesticide use and unsafe use conditions. Education programs should be culturally appropriate to achieve pesticide exposure reduction. Each method studied in this thesis can be used independently. However, they can also complement each other, providing a better understanding of the mechanisms of skin exposure. With further improvements, a combination of observation and fluorescent visual scoring techniques, both low-cost and practical, would become highly accessible methods for surveillance and for epidemiological studies in developing countries.

*Key words*: dermal exposure, developing country, pesticides, subsistence farmers, fluorescent tracer, visual scoring system, skin wipes, pesticide residues.

# Resumen

**Antecedentes:** El uso de plaguicidas sigue siendo un problema serio de salud pública en los países en desarrollo, a pesar de décadas de implementación de estrategias de “uso seguro de plaguicidas”. En Nicaragua, los plaguicidas organofosforados, en particular clorpirifós y metamidofós son responsables de casi la mitad de las intoxicaciones agudas donde la contaminación de la piel es frecuente en el contexto ocupacional. El desarrollo de métodos de evaluación de exposición dérmica se ha investigado ampliamente, aunque la aplicabilidad y factibilidad de estos métodos para países en desarrollo es incierto.

**Objetivos:** Esta tesis tiene como objetivo mejorar el entendimiento de los factores de riesgo relacionados con exposición a plaguicidas, evaluar exposición dérmica de agricultores de subsistencia nicaragüenses y proponer métodos más adecuados para países en vías de desarrollo.

**Métodos:** Se realizaron entrevistas a un grupo de 29 agricultores de subsistencia a través de cuatro grupos focales y se analizaron sus respuestas usando teoría fundamentada. Se evaluó la exposición dérmica de otro grupo de 31 agricultores mediante mediciones cuantitativas y semi-cuantitativas durante 33 aplicaciones de plaguicidas a través de observación, grabaciones de video, el uso de un trazador fluorescente, y limpieza de piel. Se modificó un sistema de puntaje visual desarrollado en Estados Unidos para adaptarlo a las condiciones de países en desarrollo. El plaguicida usado fue “marcado” durante la aplicación. La fluorescencia producida por el marcador fue observada por medio de una lámpara de luz ultravioleta portátil en un cuarto oscuro portátil, grabada en video y posteriormente medida a través de un Puntaje para Segmentos Corporales (PSC), Área Corporal Contaminada (AAC) y un Puntaje Visual Total (PVT). Los PVTs fueron utilizados como indicador en la identificación de los principales determinantes de exposición dérmica. Con éstos, se realizaron análisis uni y multivariados. 110 potenciales determinantes de exposición fueron reducidos a 27 variables agrupadas en “sitio de trabajo, equipo de aplicación del plaguicida, prácticas de trabajo, ropa, o prácticas de higiene”. Se comprobó la fiabilidad del Puntaje Visual Total mediante la determinación de los coeficientes de correlación intra clase en una sub muestra de cinco agricultores evaluados por cinco examinadores entrenados con el sistema del puntaje visual. Se analizó la exposición de las manos (contactos directos e indirectos) a través de un Índice de Contaminación con Formulado (ICF) y un Índice de Contaminación con la Solución (ICS). Los residuos de plaguicidas fueron cuantificados para las manos y áreas seleccionadas del cuerpo de acuerdo a la intensidad de la fluorescencia. Se calcularon coeficientes de correlación de Spearman para comparar los índices observacionales (ICF+ICS), el puntaje visual y los resultados cuantitativos.

**Resultados:** Las razones de prácticas peligrosas entre los agricultores estuvieron relacionadas con la pobreza, lo inadecuado del equipo de protección personal, factores climáticos, y el conocimiento limitado influenciado por creencias y tradiciones. Encontramos una relación especial e imprevista con su cultivo tradicional. Esta relación parece tener un fuerte significado en la decisión para usar plaguicidas contribuyendo a prácticas de trabajo peligrosas. Las imágenes fluorescentes en la piel de los agricultores observados reflejaron sus prácticas de aplicación y permitieron deducir los mecanismos de contaminación. Los determinantes de exposición más relevantes fueron las prácticas de trabajo, equipo de aplicación y el lugar de trabajo. La ropa usada y las prácticas de higiene fueron determinantes menos fuertes. Se identificaron varios nuevos determinantes que fueron la aplicación en terreno barroso, rocío en las plantas, sellado de la tapa del tanque con un pedazo de tela, y limpiarse el sudor de la cara. El sistema de puntaje visual resultó ser muy consistente Cronbach alfa = 0.96) y bastante fiable (0.75; 95% IC: 0.62-0.83). El ACC más alto fue de 66%. El agricultor con el PVT más alto representó el 60% del máximo posible. La espalda tuvo el Puntaje de Segmento Corporal (PSC) más alto y las manos resultaron ser las mas frecuentemente contaminadas. Este contacto de las manos fue más de tipo indirecto a través del contacto con superficies contaminadas. Todos los agricultores tenían residuos cuantificables de plaguicida en sus manos. Los coeficientes de correlación de Spearman para la observación, el puntaje visual y residuos calculados para las manos fueron entre 0.65 y 0.74 para clorpirifos y entre 0.62 y 0.87 para metamidofos. Todas menos una correlación fueron estadísticamente significativas. Las diferencias de los resultados se explican por las limitaciones inherentes de los diferentes métodos.

**Conclusión:** La pobreza así como determinantes culturales contribuyen al uso inseguro de plaguicidas. Los programas de educación deberían ser culturalmente apropiados para lograr reducir la exposición a plaguicidas. Cada método estudiado en esta tesis puede ser usado de manera independiente. Sin embargo se complementan y dan una mejor idea de los mecanismos de exposición dérmica. Con algunas mejoras, la combinación de la observación y el puntaje visual con el marcador fluorescente (ambos de bajo costo y prácticos) podrían convertirse en los métodos más accesibles para seguimientos y para estudios epidemiológicos en países en desarrollo.

***Palabras clave***: exposición dérmica, país en desarrollo, plaguicida, agricultor de subsistencia, marcador fluorescente, sistema de puntaje visual, torundas de limpieza de piel, residuos de plaguicidas.

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# Contents

# List of abbreviations

| | |
|---|---|
| BSS | Body Segment Score |
| CBA | Contaminated Body Area |
| CCI | Concentrate Contamination Index |
| CI | Confidence Interval |
| ECD | Electron Capture Detector |
| EPA | Environmental Protection Agency |
| $ES_F$ | Fenske's Extent Score |
| ICC | Intraclass Correlation Coefficient |
| LOQ | Limit of Quantification |
| NPD | Nitrogen Phosphorus Detector |
| PPE | Personal Protective Equipment |
| SCI | Solution Contamination Index |
| TCP | 3,5,6,-trichloro-pyridinol |
| TVS | Total Visual Score |
| USAID | United Stated Agency for International Development |
| UV lamp | Ultraviolet lamp |
| VITAE | Video Imaging Technique to Assess Exposure |
| WES | Weighted Extension Score |
| WHO | World Health Organization |

**Organizations/Institutions**

| | |
|---|---|
| UNAG | Unión Nacional de Agricultores y Ganaderos |
| UNAN-LEON | Universidad Nacional Autónoma de Nicaragua-León |
| UNA | Universidad Nacional, Heredia, Costa Rica |
| WHO | World Health Organization |

# Concepts and Definitions used

***Absorption***: The process by which a substance is transported across the skin permeability surface barrier and taken up into the living tissue of the body; generally synonymous with percutaneous absorption and with dermal uptake.

***Conceptual model for dermal exposure*** *(Schneider et al., 1999)*: This model refers to the processes that lead to uptake of chemicals via the dermal route. It describes uptake as a result of transport of mass between compartments. The identified compartments are: source, air, surface contaminant layer, outer and inner clothing contaminant layer separated by the fabric having a buffer capacity, and skin contaminant layer. The skin contaminant layer is separated from perfused tissue by the stratum corneum, which acts as a rate-limiting barrier having a certain buffer capacity. The proposed transport processes are emission, deposition, re-suspension or evaporation, transfer, removal, redistribution, decontamination, penetration and permeation.

***Contact volume***: A volume containing the mass of agent that contacts the exposure surface (unit = $cm^3$).

***Dermal exposure***: Contact with the skin by any medium containing chemicals, quantified as the amount on the skin and available for adsorption and possible absorption.

***Dermal exposure mass***: Mass of the agent present in the contact volume (unit = g).

***Dermal exposure loading***: Exposure mass divided by skin surface (µg or $g/cm^2$).

***Dermal exposure concentration***: The exposure mass divided by the contact volume or divided by the mass of the contact volume contained in the skin (µg or $g/cm^3$ or g/kg)

***Exposure***: Contact of a chemical, physical, or biological agent with the target organism. It is quantified as the momentaneous concentration of the agent in the medium in contact or integrated over the time of that concentration.

***Exposure determinants***: Factors that directly or indirectly influence exposures.

***Exposure assessment***: The determination or estimation (qualitative or quantitative) of the intensity, frequency, duration, and route of exposure.

***Exposure pathway***: The course a chemical or pollutant takes from the source to the organism exposed.

***Exposure route***: The way a chemical or pollutant enters an organism after contact, e.g., by ingestion, inhalation, or dermal absorption.

***Grounded theory*** *(Strauss in: Lincoln and Guba, 1985)*: Grounded theory is a theory developed inductively from a set of data. It fits therefore at least one dataset perfectly. The basic idea is to read (and re-read) a textual database (such as a corpus of field notes) and "discover" or label variables (called categories, concepts, properties and dimensions) and their interrelationships. The ability to perceive variables and relationships is termed "theoretical sensitivity" and is affected by a number of determinants including one's reading of the literature and one's use of techniques designed to enhance sensitivity.

***Hydrophilic***: The property of a chemical to have a strong tendency to bind or absorb water.

***Lipophilic***: the property of a chemical to have a strong affinity for lipids, fats, or oils; or being highly soluble in nonpolar organic solvents.

***Reliability*** *(Armstrong, White & Saracci, 1992)*: Reliability is used to refer to the reproducibility of a measure, i.e. how consistently a measurement can be repeated. Intramethod reliability is a measure of the reproducibility of an instrument, either applied in the same manner to the same subjects at two or more points in time (test-retest reliability) or applied by two or more data collectors to the same subjects (inter-rater reliability) or assess for internal consistency of the measure. Intermethod reliability is a measure of the ability of two different instruments, which measure the same underlying exposure to yield similar results on the same subjects.

***Small-scale farmers or subsistence farmers***: This thesis refers to small-scale (Paper I) (or subsistence) farmers (Papers II, III, V), who are defined as farmers growing basic grains or vegetables, owning less than ten hectares of land with no access to bank credits or technical assistance. These farmers are usually assisted by family members. Some of them receive support from non-governmental organizations.

***Uptake***: The process by which a substance crosses an absorption barrier and is absorbed into the body.

***Validity***: It indicates to which degree an assessment measures the concept it is intended to measure. Validity refers to the agreement between the value of a measurement and its true value. Validity can be quantified by comparing given measurements with values that are as close to the true values as possible.

# Formulas used

Intraclass Correlation Coefficient

$$ICC = \frac{MSP - MSE}{MSP + (k-1)MSE + k(MSR - MSE)/n}$$

n = total number of scored body surface segments by the raters

k = number of raters

MSP = between body surface segments mean square

MSE = residual mean square

MSR = between-rater mean square from two way ANOVA

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Calculation of Body Surface Area (Du Bois & Du Bois, 1916)

BSA = 0.20247 x Height (m)$^{0.725}$ x Weight (kg)$^{0.425}$

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**Concentrate Contamination Index (Eq. 1)**

$$CCI = \frac{n_{exposure-with-concentrate}}{n_{mixing}} N_M$$

**Solution Contamination Index (Eq. 2)**

$$SCI = \frac{n_{exposure-with-solution}}{n_{mixing}} N_M + \frac{n_{exposure-with-solution}}{n_{spraying}} N_S$$

where

$n_{\text{exposure with concentrate}}$ = number of videotaped hand exposure events with concentrated pesticide during mixing

$n_{\text{exposure with solution}}$ = number of videotaped hand exposure events with the spray solution during mixing or spraying

$n_{\text{mixing}}$ = number of videotaped mixing events

$n_{\text{spraying}}$ = number of videotaped spraying events

$N_M$ = total number of mixing events

$N_S$ = total number of spraying events

# 1 Introduction

Dermal exposures are known to be most relevant in the occupational setting (Sartorelli, 2002). Methods to assess dermal exposure have been largely improved in the last decade. Studies to define models (Schneider et al., 2000), understand dermal uptake of chemicals (Griffin et al., 2000; Meuling et al., 2005), linking biological monitoring to dermal absorption (Geer et al., 2004; Curwin et al., 2003), and evaluating sampling methods (Brouwer et al., 2000) have been performed to better understand and appropriately address dermal exposure. However, little is known about the applicability and feasibility of these methods in the developing world where availability, doses, environmental conditions, regulations and work practices make exposure to chemicals much more hazardous (Ecobichon, 2001; Konradsen et al., 2003; Wesseling et al., 2001c). Also, exposure assessment often implies procedures that are too costly in developing country conditions. Hence, it is important in developing countries to have available robust, reliable, standardized and low-cost methods to evaluate dermal contact.

This thesis presents the results of dermal exposure assessment performed on a group of 31 Nicaraguan subsistence farmers using three different sampling methods: observation, a fluorescent tracer and chemical residue analysis from skin wipes. Strengths and limitations of these methods are discussed from a developing country perspective. In addition, by means of qualitative approach I explore, with another group of 29 farmers, possible reasons for dangerous practices.

In this way, I wish to contribute a proposal for feasible and reliable methods to evaluate dermal exposure in developing country conditions, based on a better knowledge of pesticide exposure among this type of farmers.

# 2 Background

## 2.1 Occupational exposure to pesticides in developing countries

The majority of the workforce in developing countries is still employed in agriculture. Farmers and agricultural workers are usually poor, have bad working conditions and commonly involve their family in their work (ILO, 2000). These farmers use old, non patented, more toxic, environmentally persistent and inexpensive chemicals (Ecobichon, 2001). These chemicals are introduced into the countries with scenarios of weak regulations generally based on information from international agencies, without formal risk assessment taking into account local exposure data (Wesseling et al., 2005).

Most farmers in developing countries rely on pesticide dealers for information, use repackaged unlabeled products or products labeled with unclear instructions (Ngowi et al., 2001), mix different products in the belief that the effect will be greater, and use the available or cheapest pesticide. Additionally, the use of personal protective equipment is often impractical and expensive (Clarke et al., 1997; Ohayo-Mitoko et al., 1999; Dinham, 1996). Safety practices are also unaffordable (Murray & Taylor, 2001; van der Hoek et al, 1998;; Murray & Taylor, 2000). Pesticide containers are frequently used for storage, or left lying in fields, ditches or water courses (Dinham, 2003).

Pesticide use in developing countries has created serious health problems. It has been estimated that three million cases of severe pesticide poisonings occur world-wide every year with 220 000 deaths; most in developing countries (WHO/UNEP, 1990). Data on underreporting indicate that the extent of the problem of pesticide poisonings could be much higher (Keifer et al., 1996; Murray et al., 2002). Furthermore, chronic health effects, environmental persistence, bioaccumulation and pest resistance have been documented (Ecobichon, 2001; Alavanja et al., 2004; Bondarenko et al., 2004; Perez et al., 2000; Tilak et al., 2004). Restricting the availability of highly toxic pesticides and changes in agricultural policies towards reduction of pesticide use have been recommended to reduce these health effects (Eddleston et al., 2002; Konradsen et al., 2003; Wesseling et al., 2005).

## 2.2 Pesticide use in Nicaragua

Agriculture in Nicaragua has heavily relied on cotton production. Pesticides, such as DDT, were sprayed on cotton fields along the Pacific plain from the 1950’s onwards. Huge amounts of pesticides were used then with dramatic consequences: some 3 000 acute poisonings occurred each year during the period from 1962 to 1972 (Falcon & Smith, 1973). In 1965, Nicaragua spent

10 million US dollars on pesticides, 87% of which were for cotton (Swezey et al., 1986). During the same period USAID provided 9 million dollars of credit to buy pesticides for basic grain producers (Dosal, 1985). A production plant (HERCASA) of toxaphene was set up in Managua to sell the product to Central American countries. The rate of toxaphene application in 1985 reached 31 kg/Ha (Carvalho et al., 2003). However, cotton production decreased dramatically from the 1970's to 2003 (in 1970: 200 000 Ha, and 2003: 4 000 Ha) due to the drop of cotton prices in the international market and because the increased use of pesticides resulted in increased production costs, to the extreme that the cost of pesticides overcame the sales income.

The long-term consequences from intensive agriculture with extensive use of pesticides resulted in pest resistance, and serious ecological problems such as groundwater contamination, extensive deforestation and soil erosion. The wind erosion created clouds of dust reaching the cities during the planting season. Excessive warming of the land without vegetation and increased solar radiation dissipated ambient humidity, decreased the rains and altered the climate of León and Chinandega plains resulting in warm and dry environments (Incer, 2000).

During the 1980's the Nicaraguan Government banned a number of dangerous pesticides including DDT, lindane, phosvel, aldrin and endrin. However, after more than 40 years since the introduction of DDT and toxaphene, residues in water of the coastal lagoon of the Chinandega district still display very high concentrations of toxaphene of up to 17 450 ng/g dry weight and DDT of up to 478 ng/g (Carvalho et al., 2002).

Nicaraguan agricultural workers perform tasks of loading, mixing and applying pesticides without any protection. They also clean and repair equipment with their bare hands and use formulations of unlabeled pesticides without any knowledge of their toxicity. Legal regulations are rarely enforced (Anonymous, 1996). Programs on rational and safe use of pesticides have focused on workers' training and use of Personal Protective Equipment (PPE), but PPE use remains problematic. In a study on education programs on the use of pesticides, workers expressed that pesticides were not hazardous and that only weak individuals were at risk. They also believed that bathing after work could cause flu or arthritis and that drinking milk was effective in preventing pesticide poisoning (Weingers & Lyons, 1992). Acute occupational poisonings are still frequent. An apparent reduction of the number of reported poisonings, after almost twenty years of improving the surveillance system, turned out to go hand in hand with a 98% of under-registration according to a national community survey (Corriols et al., 2002).

## 2.3 Importance of dermal exposure and dermal uptake of pesticides

Dermal exposure has been defined as the process of contact between an agent and skin, on an exposure surface over an exposure period (Schneider et al., 1999). Exposure occurs via dermal contact, ingestion, dietary intake, and inhalation. During the last decade more attention has been paid to dermal exposure to pesticides as compared to respiratory exposure. The risk of uptake of a chemical through dermal contact has been demonstrated to be larger and more complicated to control than respiratory uptake (VanRooij et al., 1993; Semple, 2004).

Dermal uptake depends on a variety of factors related to the physicochemical properties of the active ingredient and the solvent of the pesticide, the type of skin, size of the exposed area and its integrity, and the circumstances in which the contact occurred (Fenske, 2000; Semple, 2004). It has been postulated that dermal uptake may vary according to the skin site involved. Variability of skin permeation between body segments, skin disease and wounds may locally affect the skin barrier function (Maibach et al., 1971). There are three factors affecting skin penetration. One is related to the substance such as solvent concentration, volatility, binding capacity to keratin, partition coefficient, and metabolic capacity. The second one is related to the skin such as skin hydration, skin temperature, skin circulation, skin age, and the third one is related to external factors such as contact time, humidity, occlusion and temperature (USEPA, 1992; Lidén, 2001).

There are also three types of chemical–skin interaction. The first one is related to the absorption of the chemical through the skin contributing to the systemic load; in the second one the chemical itself causes effects on the skin barrier such as irritation, burns or degradation of the barrier properties of the skin; and in the third one, the chemical causes allergic skin reactions (Semple, 2004). When a substance gets in contact with the skin, it may bind or react with the skin or metabolize in the epidermis prior to absorption. Chemicals naturally diffuse across the path of least resistance to them so that those that are only water-soluble traverse the skin largely via the aqueous pathway, whereas those that are fat-soluble use the lipid pathway. Chemicals with both lipid and aqueous solubility traverse the skin via both pathways (USEPA, 1992).

Skin contamination is known to be an important determinant of systemic acute poisoning. Systemic health effects due to dermal pesticide absorption have been widely documented (McConnell & Hruska, 1993; Wesseling et al., 2001b). Contact dermatitis is also frequent as evidenced by several epidemiological studies from Costa Rica, Panama, and Ecuador (Wesseling et al,. 2001a; Penagos et al., 2004; Cole et al., 1997). Some fungicides and insecticides cause allergic skin reaction (Lidén, 2001; Penagos et al., 2004).

## 2.4 Chlorpyrifos and methamidophos: the target pesticides

Chlorpyrifos is a commonly used broad spectrum organophosphate insecticide. Its toxicological action is through inhibition of acetylcholinesterase, a neurotransmittor. It is classified as moderately toxic (WHO class II). Due to its toxicity and exposure concerned with residential use, the US Environmental Protection Agency (EPA) recommended phasing out its residential use in June 2000. The EPA also lowered tolerances on certain crops, such as apples and cancelled use on other crops like tomatoes (Smegal, 2000). Chlorpyrifos is practically insoluble in water, but it is soluble in most organic solvents (i.e., acetone, xylene and methylene chloride). Chlorpyrifos has a low vapor pressure and is not particularly volatile. Chlorpyrifos is metabolized rapidly, and the kidneys eliminate its principal metabolites. The major metabolite found in urine is 3,5,6,-trichloro-pyridinol (TCP). From experimental studies it has been observed that on average, half of the applied amount of chlorpyrifos could be recovered from the skin surface but only 1% could be recovered as urinary metabolites. However, due to the *in vivo* nature of the experiment there is no information about the rate at which chlorpyrifos penetrated the skin (Griffin et al., 1999). The major fraction of the topically applied amount of chlorpyrifos appeared to be retained in the skin (Griffin et al., 2000).

Methamidophos is a systemic organophosphate insecticide. Its toxicological action is through inhibition of acetylcholinesterase. It is classified as highly toxic (WHO class Ib). The EPA has classified methamidophos as a restricted use pesticide (RUP) in the US due to its high toxicity. Methamidophos can also be the product of metabolic conversion from acephate. Methamidophos is water-soluble. It is excreted in the urine unmodified. When S-Methyl-14C methamidophos is administered, volatile metabolites are formed, the main one of which is the unstable compound methylmercaptan ($CH_3SH$). Experimental data (rat, monkey and human) about the absorption of methamidophos are said to be consistent with the hypothesis that methamidophos is metabolized or degraded to methylmercaptan on the skin surface and that this is either lost by volatilization or bound to proteins of the skin. Therefore, it has been suggested that dermal absorption of methamidophos through human skin is significantly lower than 10% (EFSA, 2004). Table 1 summarizes the physical properties of both pesticides.

**Table 1**. Technical description of the two pesticides under study

| Physical properties | Chlorpyrifos | Methamidophos |
|---|---|---|
| **Appearance** | Technical chlorpyrifos is an amber to white crystalline solid with a mild sulfur odor | Crystalline solid, with off-white color and pungent odor |
| **Chemical name** | O,O-diethyl O-3,5,6-trichloro -2-pyridyl phosphorothioate | O,S-dimethylphosphora-midothiolate |
| **CAS number** | 2921-88-2 | 10265-92-6 |
| **Molecular weight** | 350.62 | 141.12 |
| **Water solubility** | 2 mg/L at 25 degrees C | 90g/L at 20 degrees C |
| **Solubility in other Solvents** | Benzene s.; acetone s.; chloroform s.; carbon disulfide s.; diethyl ether s.; xylene s.; methylene chloride s.; methanol s. | Data not available |
| **Melting point** | 41.5-44 degrees C | 44.5 degrees C |
| **Vapor pressure** | 2.5 mPa at 25 degrees C | $3 \times 10^{-4}$ mmHg at 30 degrees C |
| **Partition coefficient** | 4.6990 | -1.74 |
| **Adsorption coefficient** | 6070 | Data not available |

Sources: http://extoxnet.orst.edu/pips/chlorpyr.htm, http://extoxnet.orst.edu/pips/methamid.htm

## 2.5 Exposure assessment

In epidemiology, exposure denotes any of the subject's attributes or any agent with which he or she may come in contact that may be relevant to his or her health (Armstrong et al., 1992). In case of exposure to a chemical agent, exposure assessment determines the degree of contact a person has with a chemical and estimates the magnitude of the absorbed dose. There is a distinction between *exposure measurement* and *exposure assessment*. The first is limited to the quantification of exposure, and the second extends to the implications of the exposure level that has been measured. The use of adequate exposure assessment methods is of extreme importance in agricultural settings. Very much effort has been dedicated to studying, proposing and testing the most appropriate methods to understand and evaluate exposure.

There are several factors that can influence degree of dermal exposure. These include reductions or increases in chemical contact with skin due to normal clothing, use of protective clothing and gloves worn by workers, individual differences in dermal exposure due to differing degrees of speed, care, and dexterity in performing work, variances in the penetrability of the skin in different parts of the body, individual variability in regard to skin penetrability due to age and skin condition, and the physical properties of chemical contaminant (USEPA, 1992; Schneider et al., 2000; Kromhout et al., 2004).

## 2.6 Measuring dermal exposure

Dermal exposure to chemicals was evaluated as early as 1880 (Fenske, 2000). The development of methods to assess dermal exposure has considerably increased since the last decade (Semple, 2004; Fenske, 2000). However, due to the complexity of interaction between a substance and the skin, there are still large gaps in the documentation and validation of sampling methods (Schneider et al., 2000). Dermal exposure can be evaluated with qualitative methods such as observation, with semi-quantitative methods such as fluorescent tracers and the visual scoring system, and with quantitative methods such as skin removal techniques. The most common ones have been those that quantified pesticide residues deposited on the skin via surrogate sampling (gloves, patches) or by removal such as washing, skin wiping or tape stripping. In the last 20 years, a new technique has been developed to visualize the contact of chemicals with the skin and determine the mass deposited on skin which is based on fluorescent agents (Fenske et al., 1986). There have also been efforts to use deterministic methods to help estimate the amount of chemicals likely to be deposited on the skin through exposure modeling (Schneider et al., 1999; van Wendel de Joode et al., 2003).

### 2.6.1 Qualitative methods: observation

Observation has been used in occupational health as a complement to exposure assessment methods, application of questionnaires, and as a preliminary task for hygiene evaluation. Observation is considered a direct and objective method of exposure measurement in epidemiology (Armstrong et al., 1992). Observation is useful for understanding the context and it also provides a basis for interpreting quantitative results. When the observation is accompanied by video technology, videotapes can also be used as a mechanism for feedback. Video observation opens the possibility of having a revisable documentation from the field. This documentation can serve both as a source of data collection to be used in research or evaluation as a historical record and as a basis for a detailed occupational hygiene assessment.

### 2.6.2 Fluorescent tracer

The fluorescent tracer technique seems to be a very simple method for visualizing exposure. The observation of the contaminated skin of a person recently exposed to pesticides during an application day, by using such a tracer has demonstrated that it is a rapid and simple option for assessment of exposure. These tracers have previously been used for identification of leakage from pipes and circulating physical systems. For hygienic purposes, the fluorescent tracer was first used in 1950's, to evaluate performance of protective clothes (Houghton et al., 1998). Later on, Fenske et al. (1986) developed the Video Imaging Technique to Assess Exposure (VITAE), which transformed qualitative observations of fluorescent skin images into quantitative values by means of a computer program. VITAE has been shown to perform well with substances such as malathion (Fenske, 1988a) and primicarb (Archibald et al., 1995). It has also contributed to the understanding that pesticide skin deposition is not uniform. In 1988(b), Fenske also developed an accessible semi-quantitative method with a score based on the area and the intensity of the fluorescent tracer observed on the skin called a "Visual Scoring System". This Visual Scoring System was validated and correlated well with the computerized VITAE. The validation was made by means of reading photographs although he suggested the use of videotapes by freezing the images. Using the method quantitatively it is supposed to evaluate skin loading more accurately than other methods. However, it has been difficult to demonstrate the accuracy of the method (Fenske, 2005).

### 2.6.3 Removal techniques

Skin exposure can be estimated by wiping, washing, or tape stripping. Skin wiping has been defined by Brouwer et al. (2000) as "the removal of contaminants from skin by providing manually an external force to a medium that equals or exceeds the force of adhesion over a defined surface area". The material used, generally a gauze-pad, is usually impregnated with a solvent to wipe the skin and remove residues (Geno et al., 1996). The amount of chemical removed from the skin at the time of sampling does not really represent the actual skin loading. Removal methods may also be influenced by the characteristics of the skin and may be of limited use for repeated sampling. Criticisms of the techniques have been that skin wiping and hand washing will not recover residues that are absorbed into skin. They can also show a high degree of variability in recovery efficiency, and are also of limited use when the substance under study is either highly volatile or likely to be rapidly absorbed by the skin (Brouwer et al., 2000; Wester & Maibach., 1985).

McArthur (1992) summarized the problems with removal efficiency as related to the observer (the technique used must avoid spreading the chemical), the chemical itself (some are more easily removed), the depth of surface contamination (excess is more easily removed, removal efficiency decrease with decreased skin loading) and the solvent used that facilitates the removal.

Although skin wiping has increased in recent years, to date there is no standard protocol for this technique, and skin wipes have been demonstrated to under-estimate skin loading (Brouwer et al., 2000; Fenske 2005). In a study with apple thinners it has been estimated that skin wipes would only recover 10% of the true exposure (Fenske et al., 1999). The only study that showed a good recovery efficiency even exceeding 100% was based on wiping immediately after exposure. According to Fenske (2005) there was probably an overestimation due to repeated measurements of the same farmers on consecutive days. Adjustments are suggested to use and standardize the technique for dermal exposure measurements.

Skin washing is a method mostly used for the hands. It is also called hand rinsing. There are basically two ways of performing hand washing, by scrubbing the skin by mechanical agitation removing the contaminant by a combination of mechanical forces and chemical action, or by pouring the liquid removing the contaminant by a combination of hydrodynamic drag and chemical action (Brouwer et al., 2000). The method has demonstrated good reproducibility in laboratory studies. A comparative study showed a better removal with hand washes than with skin wipes. Limitations with the handwash are that it does not seem to remove the total amount deposited on the skin (Fenske & Lu, 1994) and that it requires large quantities of volumes to be transported to the field. There are no standard approaches, and sampling efficiency tests have not been performed either. Brouwer et al. (2000) in their review stated that the type of solvent, soap, water hardness and temperature may affect the removal efficiency of hand washes.

Tape stripping is an experimental method used under laboratory conditions. It has been recently tested for acrylates (Nylander, 2000) and jet fuel (Mattorano et al., 2004) and consists of placing at least two consecutive adhesive tapes on skin and later detaching them to remove the stratum corneum in skin areas where single doses of a chemical were applied. The residues recovered with the adhesive tapes are then analyzed with gas chromatography. This technique is useful for assessing the rate and extent of dermal absorption in vivo, which can potentially be used to test the permeability of a substance (Reddy et al., 2002).

## 2.7 Methodological requirements of exposure assessment in the developing countries

Besides the technical knowledge for research in occupational health, it is important that research is contextualized and uses both qualitative and quantitative methods (Mergler, 1999). Methodological studies in developing countries require an understanding of not only the hazards deriving from being in contact with toxic substances but also understanding farmers' knowledge, values and beliefs (Nuwayid, 2004). Occupational disease determinants are often masked by the combined effects of work, wider environmental risks, and a high rate poverty-related diseases (Loewenson, 2004). Results from studies performed in developed countries may not be applicable to developing country conditions, where exposures may be much higher and circumstances, such as poor nutrition, poor health status, environmental contamination, and extreme climatic conditions, may enhance risks. Unfortunately, developing exposure assessment studies in developing countries is too expensive; risk evaluation is usually based on poorly interpreted experimental studies performed in the developed world. The results are not applicable to real-life situations in poor countries (Wesseling et al., 2005).

In developing countries we must be aware, when studying agricultural populations, that there will be large variability of exposure in between-worker behavior and exposure conditions, and in within-individual substance deposition and skin interaction in various body areas (Kromhout et al., 2004; Semple, 2004). It is also recommended that for a better understanding of exposure, farmer's perception, constraints, motivations and hygienic behavior should also be taken into account (Fenske, 2000).

# 3 Objectives

## 3.1 General objective

To increase the understanding of risk factors underlying exposure, evaluate dermal exposure among Nicaraguan subsistence farmers, and propose suitable methods for developing country conditions.

## 3.2 Specific objectives

- To understand cultural and socio-economic reasons for dangerous practices of agricultural workers in Nicaragua in relation to use and hazards of pesticides (Paper I).

- To define main exposure determinants during pesticide application among Nicaraguan small farmers (Paper II).

- To evaluate skin exposure with an adapted version of a visual scoring system using a fluorescent tracer; test its reliability; and discuss strengths and limitations of the use of the fluorescent tracer for qualitative and semi-quantitative assessment of dermal exposure in the context of a developing country (Paper III and IV).

- To compare and evaluate different methods of assessing hand exposure to pesticides (Paper V).

# 4 Subjects, materials and methods

## 4.1 Paper I

### 4.1.1 Study population

The participants were 29 male independent small-scale or subsistence farmers. Most of them were affiliated to rural peasant organizations. They were interviewed in four focus groups. Group members were selected by looking at a broad variation of personal views of their work as independent farmers.

### 4.1.2 Data collection

Each group met once on neutral premises. No persons other than participants and the moderators were present during the meetings. The meetings lasted between two and three hours. The sessions were recorded on tape and later transcribed. When one was moderating, the co-moderator made observations and took notes on group dynamics represented by interactions between the participating farmers.

### 4.1.3 Data analysis

Data analysis was based on grounded theory (Starrin et al., 1996). Two of the authors independently examined the transcripts searching for recurrent patterns and regularities. Coding was done with the help of the computer program Open Code (1997). The analysis of the first two groups guided the topics addressed in the next groups. Codes from all four groups were scrutinized, compared, discussed, categorized and integrated into themes.

## 4.2 Papers II to V

### 4.2.1 Study population

The study group consisted of subsistence farmers in western Nicaragua (León & Chinandega). Participants were selected just before the application season at meetings with the local Farmers' Association. The 40 farmers, who reported that they were planning to use methamidophos or chlorpyrifos, were shown how the fluorescent method worked and informed about the study design. All of them were willing to participate and signed an informed consent. Farmers were told they could spray at any time when they felt that it was necessary. Change of date of pesticide spraying, use of pesticides other than the two organophosphates, and difficulties of farmers in contacting the researchers, reduced the participants to 31, six of whom participated in the pilot phase of the study. Two farmers were evaluated twice, resulting in 33 applications observed (Table 2). The results of one farmer, who applied cypermethrin, were not used in papers IV and V.

**Table 2**. Characteristics of the pesticide applications.

| Active pesticidal ingredient | Hectares sprayed Median (Range) | Application time (minutes) Median (Range) | Type of backpack | |
|---|---|---|---|---|
| | | | Manual | Motor |
| Chlorpyrifos (n=12) | 1.2 (0.7 - 4.2) | 38 (17 - 119) | 3 | 9 |
| Chlorpyrifos and deltamethrin (n=1) | 0.7 | 26 | – | 1 |
| Chlorpyrifos and methamidophos (n=4) | 0.6 (0.5 - 4.2) | 32 (15 - 87) | 2 | 2 |
| Methamidophos (n=13) | 0.7 (0.4 - 2.8) | 47 (10 - 93) | 6 | 7 |
| Methamidophos and cypermethrin (n=2) | 1.0 (0.7 - 1.4) | 64 (23 - 105) | 1 | 1 |
| Cypermethrin (n=1) | 0.7 | 46 | 1 | |
| Total | | | 13 | 20 |

### 4.2.2 Exposure assessment

At the beginning of the application day, each subject was examined in a portable darkened room under a long-wave (365 nm) ultraviolet light (UV-A or black light) to identify natural fluorescence in body surfaces and for videotaping. At the end of the shift, the farmer was observed again in the darkened room for fluorescent images and for skin wipes both in body areas with different grades of fluorescent intensity and the hands. Table 3 summarizes the number of samples taken with each technique that are reported in this thesis.

**Table 3.** Number of subjects sampled by technique and type of pesticide.

| Pesticide applied | Observations | Videotapes | Fluorescent tracer scores | Wipes of fluorescent areas | Hand wipes |
|---|---|---|---|---|---|
| Chlorpyrifos | 12 | 12 | 12 | 8 | 12 |
| Chlorpyrifos and delthametrin | 1 | 1 | 1 | 1 | 1 |
| Chlorpyrifos and methamidophos | 4 | 4 | 4 | 4 | 4 |
| Methamidophos | 13 | 11 | 12 | 11 | 13 |
| Methamidophos and cypermethrin | 2 | 2 | 2 | 2 | 2 |
| Cypermethrin | 1 | 1 | 1 | 0 | 0 |
| Total | 33 | 31 | 32 | 26 | 32 |

**Observations**

A checklist for observation procedures was prepared based on the authors' previous experience in pesticide matters, reinforced by a series of visits to small farmers just prior to the study. The checklist items concerned pesticide handling before the application and during loading and spraying (transport, mixing, loading, spraying and waste management) up to the moment the farmer stored the equipment and any pesticide leftovers. Notes were made of extraordinary events that occurred during the application. Data on clothing, personal protective clothes and climatic conditions were recorded.

**Hygiene evaluation with video recording**

Videotaping was used to complete the recording of events. More than five loads were videotaped intermittently, taking care that relevant events were either annotated and/or videotaped. Exposure events were evaluated in terms of how contact with the pesticide occurred.

**Fluorescent tracer visualization**

The tracer used in this study was Tinopal CBS-X® (260mgs /L) [Disodium 4,4' –bis(2-sulfostyryl) biphenyl]. Tinopal is an optical brightener which absorbs short wave UV energy (340-400 nm) in daylight. It has good water solubility. Immediately after spraying, subjects were videotaped with a handycam with an 8-mm cassette, inside a 1.2 x 1.2 x 2 m foldaway dark room designed for the purpose. The room consisted of wood frame walls and roof, and a black synthetic leather cover that can be put together by means of Velcro®. To simplify the simultaneous observations and recording of the fluorescence, the lamp was attached to the video camera by the investigators holding them together. The camera-and lamp-to-subject distance ranged from 30-50 cm. No zooming was applied to the camera while observing. To reach the focus, we usually started at a contaminated area, and then followed towards clean areas. Several few-minute breaks were scheduled during the recording process because of increases in the ambient temperature. The video recording took between 30 – 60 minutes for each farmer. A characterization of the fluorescent images and guidelines to facilitate reading were developed (Paper III).

**Scoring system, modifications and reliability test**

A semi-quantitative method was originally developed by Fenske (1988). It is based on a matrix where the ordinate represents the exposed area (extent) of a specific body area and the abscissa denotes exposure intensity. The extent is classified into five categories (≤20%, 21–40%, 41–60%, 61–80%, and 81–100%) and exposure intensity is represented by a scale of low (1), moderate (3), and high (5). The product of these two ranks results in a score for the image ranging from 1 to 25. Modifications made to the scoring system were the observation of most of the whole body surface by segments (face and front and back of neck, thorax, arms, forearms, hands, thighs, legs and feet resulting in 31 body segments) excluding genitalia, buttocks and the back of the head (9.5% of the total body surface) (Paper III) (Figure 1). Some body segments were expected to be clean. Therefore a zero score was added to the matrix.

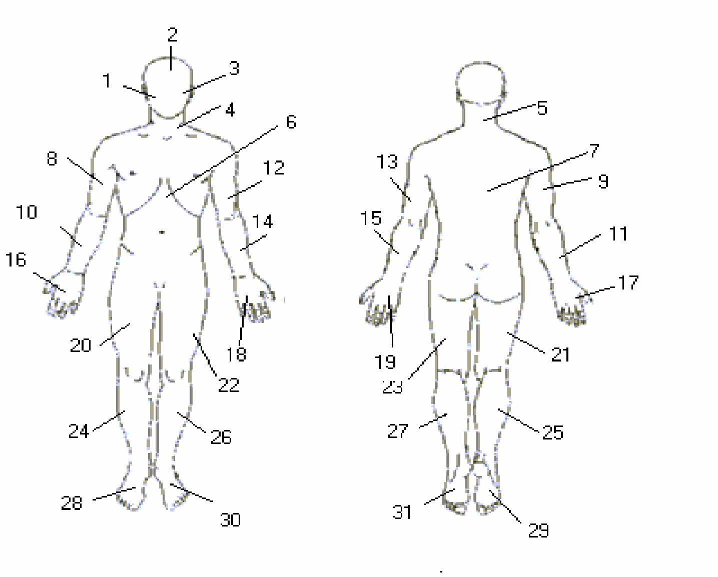


**Figure 1**. The 31 body segments distributed in the front and back part of the total body area.

Figure 2 shows the left palm of a farmer with fluorescent depositions. We started the reading by discriminating the extent of the contaminated body segment by first deciding the percentage of clean or non-fluorescence in the observed body segment. Three basic contamination patterns identified for the reading were splashes, mist and friction; for each type, categories of low, moderate and high were developed. Figure 2 shows the contamination of a hand and the score given. More than 80% of the palm is "contaminated" (score = 5), the dominant pattern is smear, and the dominant intensity is high with some moderate and a few low intensity spots. Therefore a score of 4 for intensity is given. The product of extent and intensity is the BSS of the left palm of the hand, which is 20.

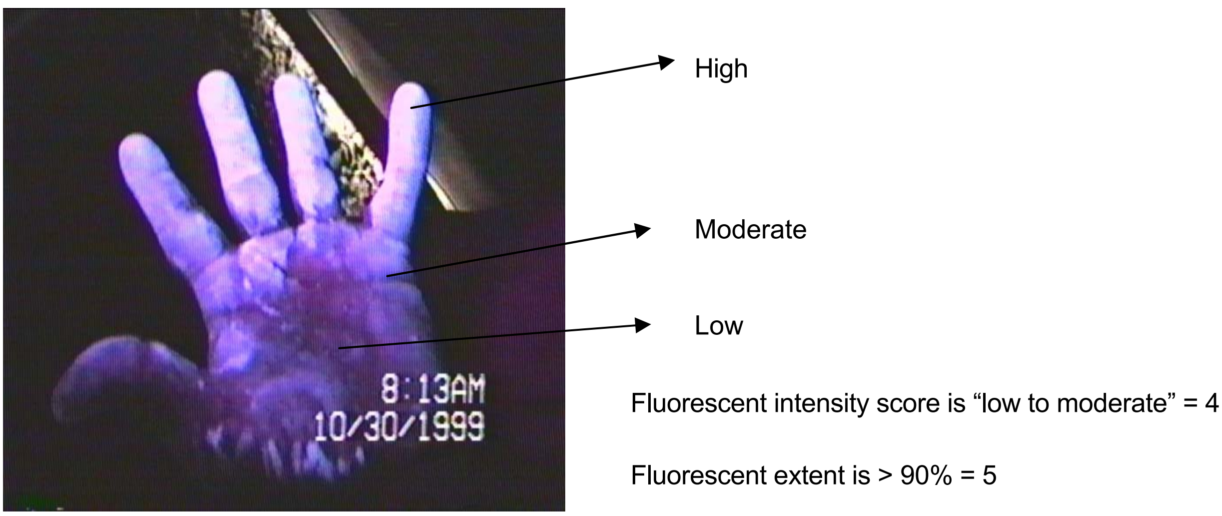


**Figure 2**. Example of scoring contamination of the left palm of a hand

To test the reproducibility of the method, five videotapes corresponding to five farmers were randomly selected from the 24 applicators with the most complete data (≥28 scored body segments). Five students in the fifth year of medical school, with an interest in occupational health, were invited as raters (R1-R5). They had not previously been connected with the study or with the farmers, and did not participate in the data collection. Two of the authors conducted the training, which took four hours and included theoretical background of the use of fluorescent tracers and practical training. The rating of the main investigator, who had previously scored the farmers, was included for comparison as Rater 6 (Paper IV).

**The components of the Visual Score**

Considering that body segments have different sizes, the scoring system was modified by weighting the extent scores of the specific body segments by their proportion of the whole body. The weights are based on the percentages of the Lund & Browder chart used to estimate affected area in burned patients in relation to Body Surface Area (BSA) (Lund & Browder, 1944). The procedure and formula used to convert previous scoring of the exposed area (extent) to the corresponding percentage of BSA is explained in Paper III. With the modifications, three measures were obtained:

- Body Segment Score (BSS), which is essentially the same as what Fenske proposed, plus a "zero" score for clean areas and the adjustment by size of body segment.
- Contaminated Body Area (CBA) which is the use of only the extent (area exposed) component of the Visual Score by summing up the contaminated proportions of all body segments.
- Total Visual Score (TVS) which is the sum of all BSSs.

**Skin wiping in the field and laboratory analysis**

For each farmer twelve 8.5x5 cm gauze-pads were previously prepared at the laboratory. The gauzes-pads were impregnated with 2 ml isopropanol and introduced in 12 ml glass vials with a teflon-lined cap. In the field, gauze-pads were removed from the glass vial by one of the researchers using tweezers previously cleaned with acetone. After observation and videotaping in the darkened room, a selection of 2 to 6 body areas with different degrees of fluorescence intensity was made. Immediately after, wiping was performed on the selected skin areas and also on a non-fluorescent area, marking the contours of the wiped area on a plastic wrap. This wrap was later weighted to calculate the wiped surface. The hands were wiped ten times on each side as described in Paper V.

At the laboratory, sample extraction and analyses were conducted for chlorpyrifos and methamidophos at the pesticide residue laboratories of the Universidad Nacional Autónoma de Nicaragua (UNAN-León) and Universidad

Nacional (UNA) in Costa Rica, respectively. The extracts were analyzed with capillary gas chromatography using splitless injection. For chlorpyrifos an Electron Capture Detector (ECD) was used, and for methamidophos a Nitrogen-Phosphorus Detector (NPD). The limit of quantification (LOQ) in the wipe samples obtained by the laboratory was 0.04 mg for chlorpyrifos and 0.1 mg for methamidophos.

**Data analysis**

The observed events during loading and application were treated in two ways, with qualitative and quantitative approaches. Observed events related to direct or indirect contact with the skin were listed for the whole body, focusing particularly on the hands. The above helped to define main exposure determinants (Paper II) of total dermal exposure and also elaborate a separate list of those that affected the hands (Paper V). The frequency of events related to hand contact was transformed into semi-quantitative data by using two contamination indexes: the Concentrate Contamination Index (CCI) and the Solution Contamination Index (SCI) (Paper V).

Descriptions of the analyses performed to test each method are contained in the respective papers (II-V). Univariate and multivariate models were constructed to identify dermal exposure determinants that predicted TVSs (Paper II). To test if the intensity score of the Visual Scoring System represented loading (µg/cm$^2$), the amount of residues recovered from the skin were correlated with the different degrees of intensity (Figure 2, Paper III). The intensity score was also tested for sensitivity and specificity comparing ”clean” and ”contaminated” areas, with amounts of residue recovered from the same areas using the residues as the ”gold standard”. Reliability was tested using the two-way random model of intraclass correlation coefficients (ICC) with measures of absolute agreement and Cronbach alpha coefficient (Paper IV). We have also correlated the contamination indexes (Concentrate Contamination Index (CCI) and Solution Contamination Index (SCI), with the amount of the residues removed from both hands (µg/m$^2$) and the fluorescent BSS of the hands with amounts of residue (Paper V).

All the studies have been approved by the Ethical Committee of the Faculty of Medicine at the Universidad Nacional Autónoma de Nicaragua in Léon.

# 5 Results

## 5.1 Farmers' views

Qualitative results as presented in Paper I showed farmers' views concerning their reasons for unsafe practices. Those views turned out to be within four categories or themes. The first theme was *Poverty*, leading to dangerous practices such as the use of inferior equipment, not using proper clothing, failure to adopt slower, non-chemical pest control methods and an increased work pace favoring both pesticide absorption and heat stress. The second theme was *Inadequacy of personal protective equipment*, which was considered uncomfortable and therefore unacceptable. The applicators got stuck in the mud when wearing boots slowing down their work pace and at the same time increasing the strain. Gloves usually got wet inside, increasing the contamination risk. *Knowledge* was the third theme; Farmers recognized the risk of the pesticides and the routes of absorption, although they thought inhalation and ingestion were more important. The strong smell of a pesticide was considered a warning sign and the use of a wetted handkerchief, better protection than a mask. Milk or enough food before the application was thought to be protective. The fourth theme was *Relationship*; Farmers expressed a familiarity and affection with the crop that made them see the pests as disease and the pesticide as an unwanted but necessary fast medicine to rapidly "cure" the threat to their crops.

## 5.2 Spraying and protection

Farmers evaluated with current exposure sprayed with either two types of backpack sprayers: 10 L motorized or 18 L manual. Pesticide concentration in the solution was significantly higher for the motorized backpack sprayer (range 4.3 to 9.2 g/L) as compared to the manual backpack (range 1.2 to 3.0 g/L). Spraying time was significantly shorter for the motor-pressurized backpacks compared to the manually pressurized backpacks (mean 69.5 min vs 32.4 min, $p = 0.002$). None of the farmers used protective gloves and very few ($n = 5$) wore shoes. Shirts, t-shirts and trousers worn were old, worn-out or frayed (Table 4).

## 5.3 Exposure determinants

Exposure determinants elicited from dermal pesticide exposure among these subsistence farmers are described in Paper II. In summary, 110 potential exposure determinants were reduced to 27 variables. Of this list, there were 19 variables showing increased visual scores (Table 1, Paper II): six significantly (temperature, using a hand-pressurized backpack sprayer, volume of sprayed dilution, spraying with nozzle directed in front, splashing on the

**Table 4**. Clothes worn by farmers the day of the application (n=32)

| Protection/clothes used | Frequency | Percent |
|---|---|---|
| *Wearing cap/head gear* | | |
| Yes | 27 | 84 |
| No | 5 | 16 |
| *Type of shirt* | | |
| Short-sleeved/long-sleeved rolled up | 16 | 50 |
| long-sleeved/two shirts | 15 | 47 |
| Non-sleeved | 1 | 3 |
| *Shirt condition* | | |
| Good | 13 | 41 |
| Bad (old/overused or torn) | 19 | 59 |
| *Type of pants* | | |
| Long | 24 | 75 |
| Knee-high (short or long rolled-up) | 8 | 25 |
| *Hand protection* | | |
| No | 32 | 100 |
| Yes | 0 | 0 |
| *Shoes used* | | |
| Slippers/none | 27 | 84 |
| Leather/rubber boots | 3 | 9 |
| Sneakers/shoes | 2 | 6 |

feet, and gross contamination of the hands). Eight determinants correlated negatively with the total visual score: height of the crop, applying on a slightly sloping terrain, wearing a long-sleeved shirt, wearing long trousers, wearing shoes, nozzle height, sealing the tank lid with a piece of cloth as protection, and having a helper. Work practices influenced the visual score most strongly explaining 52% of the total visual score variability. In the across-group multivariate regressions, the sprayed surface, spraying on a wet or slightly muddy terrain, using a manual backpack sprayer, and significant skin contamination by touching directly the spray solution (blocking a leakage or entering the hands into the tank) emerged as the strongest determinants for increasing the total visual score, whereas wearing long trousers emerged as the main preventive factor. The variability explained by the model was 69 %. An extended model also including non-significant variables explained 75% of the variability in the visual score.

## 5.4 Fluorescent tracer and visual scores

Modifications made to the visual scoring system were tested for validity (Papers III and V) and reliability (Paper IV). Most common fluorescent deposition observed among these farmers was smear, which was related to indirect contact with contaminated surfaces and redistribution by friction or transfer from one surface to the other. This observation corresponded to the high SCI observed (Paper V). Splash and mist, and combinations of patterns were also observed. These patterns indicated pathways such as the transfer of the contaminant from the source to the skin via emissions into the air and deposition on the face observed (Paper V). Splash and mist, and combinations of patterns were also observed. These patterns indicated pathways such as the transfer of the contaminant from the source to the skin via emissions into the air and deposition on the face.

Depositions were most frequently observed on the front and back of hands (>87% of the farmers), the front of the left forearm (75%), and the back of the trunk (75%). Depositions were less frequently observed on the front of the right upper arm (19%) and the back of the right thigh (19%). The highest Body Segment Score (BSS) among contaminated farmers, by far, was observed for the back (mean 28.6, range 2.6 – 65.0) (Figure 3). The highest TVS represented 60% of the maximum possible.

Correlation of fluorescent intensity levels were mostly in accordance with pesticide residues (Spearman correlation coefficient = 0.63, both for chlorpyrifos and methamidophos) although there were signs of misclassification mainly for the low contaminated areas. Reliability tests for BSSs were 0.75 (95%CI 0.62 – 0.83) for ICC and 0.96 for Cronbach alpha.

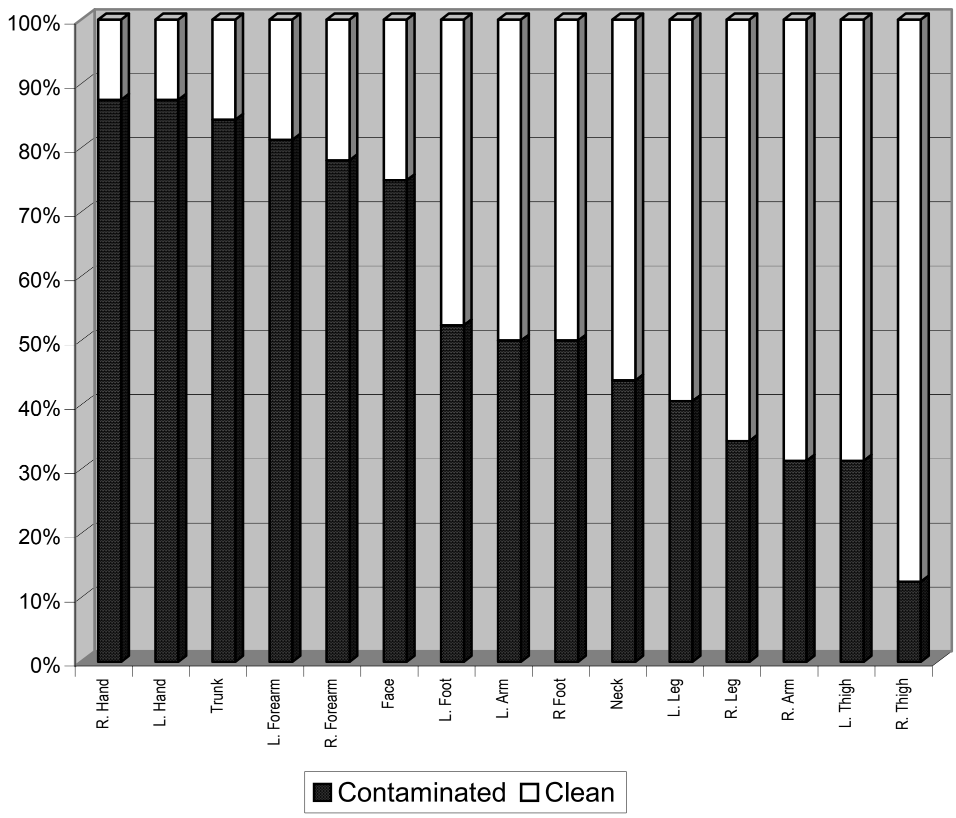


**Figure 3**. Proportion of farmers with fluorescent depositions according to body areas.

## 5.5 Hand exposure evaluation

Indirect contact occurred more frequently than direct contact both in relation to the pesticide concentrate and the spray solution. The most common events of indirect contact were touching contaminated surfaces (backpack, pesticide container, measuring device, leaves, and pieces of plastics and cloth). The most common events of direct contact were touching leakages and fumbling with the equipment.

Spearman correlation coefficients of the three indicators of hand exposure (observation indices, visual fluorescent score and pesticide residues) showed that the lowest correlation coefficient (0.48) was between residue levels and visual fluorescent scores, but the correlation increased to 0.76 after excluding farmers who rinsed their hands before sampling (n = 6 farmers, 7 samples). The observational scores correlated better with the level of residues after stratification by type of pesticide. Correlations ranged from 0.65 to 0.74 for chlorpyrifos and 0.62 to 0.87 for methamidophos. With one exception, all correlations were statistically significant at the 95% level.

# 6 General discussion

## 6.1 Introduction

This study addressed methods of assessing current dermal exposure, as tested among subsistence farmers in Nicaragua. Dermal exposure assessment methods were adapted to the particular context of Nicaragua. Three techniques were used: a quantitative (skin wipe), a semi-quantitative (fluorescent tracer with a visual scoring system), and another semi-quantitative method based on the observed number of contacts with pesticides during application. The three methods showed moderate to good correlation ($r = 0.48$ to $0.87$). Tests for reliability were performed for the fluorescent tracer method showing good inter-observer agreement. Using the TVS as the criterion variable for exposure (representing the presence of pesticide on the skin), dermal exposure determinants among these farmers were identified. The strongest determinants and several others matched the hazardous practices and conditions mentioned by farmers during the qualitative interviews. The combination of qualitative and quantitative methods improved the understanding of dermal exposure which seemed to be linked to cultural, social and economic determinants.

Occupational exposure evaluation for a long time emphasized assessing inhalation exposure and finding ways to reduce the health risks (Schneider et al., 1999; Sartorelli, 2000). Although dermal exposure to pesticides has been measured for almost 50 years (Durham & Wolfe, 1962; Franklin et al., 1981), during the last decade a great deal of effort has been made to assess dermal exposure in a variety of occupations (van Wendel de Joode et al., 2005a,b; Semple, 2004). The skin is now acknowledged to be an important route for any kind of exposure and the primary route of exposure to pesticides for agricultural workers (Fenske & Elkner, 1990; Schneider et al., 2000).

Several techniques such as surrogate or interception, removal techniques, fluorescent tracers and biological monitoring have been used and evaluated alone or combined with each other for dermal exposure assessment (Fenske, 1993; van Hemmen & Brouwer, 1995). However, not all the methods for evaluating dermal exposure have been standardized or validated and sampling protocols have not been harmonized to compare groups (Brouwer et al., 2000). Evaluating dermal exposure is a complex task. Chemical-skin interaction results in large variability among exposed groups and within the groups (Kromhout et al., 2004). There is a need for developing simple tools to assess and control the risks of dermal exposure in small and medium-sized workplaces (Marquart et al., 2001). In the last decade, scientific workshops (http;// www.iom-world.org/news/ppworkshop), large projects (RISKOFDERM) and numerous papers have been produced proposing standardized terminology, sophisticated and simple easy-to-use methods and models to evaluate dermal exposure (Schneider et al., 1999; 2000; Cherrie et al., 2000; van Wendel de Joode et al., 2003). Since little is known about the applicability of these methods in countries like Nicaragua, and exposure assessment implies costly procedures that are often unfeasible, a clear need exists for valid and reliable methods that can be applied at low cost and in the specific field conditions of pesticide exposure. The currently available methods should be adapted to allow evaluation of dermal exposure in this type of working population.

## 6.2 Validity and Reliability

### 6.2.1 Information search and selection of methods

When planning this investigation, we wanted the methods for evaluating dermal exposure to be reliable and low-cost for Nicaragua and comparable countries. Selection criteria (methods already tested and previously used in other studies, availability of materials and equipment in the country, and the possibility to transport the equipment to the field over the bad roads and paths) were based on an extensive literature review (Franklin et al., 1981; Fenske et al 1986; Fenske & Elkner, 1990; McArthur, 1992; Fenske & Lu, 1994; Archibald et al., 1994, 1995; Geno et al., 1996; Lonsway et al., 1997 Roff, 1994). With the available information, three methods were selected for dermal exposure; hygiene observations with videotape, a fluorescent tracer technique with a visual scoring system and the skin wipes. From them, only the visual scoring system has been validated against VITAE (Fenske, 1988b). For skin wipes there was no standard protocol, nor clear instructions of the sampling procedure (Brouwer et al., 2000), and for hygiene observations, instructions of walk-through check lists were found but had to be adjusted to exposure conditions identified in prior visit to this type of farmers. Besides, innovations were made in the sampling procedure to remove residues deposited on the skin of areas with different degrees of fluorescence (Paper III).

### 6.2.2 Pilot study

A pilot study was performed to pre-test all selected methods. We wanted to know if the instruments were appropriate or complicated, if the research protocol was realistic and workable, to identify logistical and practical problems in following the research procedure, to determine what resources (staff and finance) were needed for the planned study, and to train the researchers in as many elements of the research process as possible. A training session was conducted on a farm simulating pesticide application with a backpack sprayer, to practice the performance of data collection techniques and the sequence of methods. Next, four farmers spraying chlorpyrifos and two spraying methamidophos were recruited from Chinandega and León. Each technique was discussed among the researchers and adaptations were made to better suit the working conditions.

The changes made during the pilot study concerned improvements in data collection as well as ethical aspects. Changes for data collection included sequencing of methods, the way of using the video-camera, timing for observations in the dark room, on-site scoring of the fluorescent areas, registration of skin area wiped after the application, storage, transportation of samples, and numbers of visits needed. Ethical improvements included the provision of eye protection for the farmer for UV illumination and changing the reading of skin fluorescence from on site, to a posterior reading of the videotape to shorten time and to prevent an increased absorption of the pesticide deposited on the skin due to sweating.

### 6.2.3 Field conditions

To avoid differential exposure measurement errors (Armstrong et al., 1992), an operational protocol manual was developed with clear instructions for data collection of each method including the equipment, list of materials and sequencing of sampling. In addition, each researcher had the responsibility to perform one or two tests from the beginning to the end of the data collection period. To avoid errors related to the knowledge of degree of exposure, samples were sent to the laboratory without personal identification. In the field, two people took care of the observation and videotapes, one annotated observations on the form, and another person videotaped the application. Exposure events that could not be detected during the observation on site were later rechecked on the videotapes of all participants. Concerning handling of the tracer, to avoid false positives, the tracer was always poured into the tank by the same researcher. The same two researchers videotaped the fluorescence following the same routine according to the protocol. Skin wipes were performed by two other researchers. The sequence of wiping was always the same and care was taken that while one of the researchers was wiping the other one was labeling the vial with the corresponding code. Wiping was performed in the same way ten times on each side using one gauze pad according to a protocol of the University of Washington (Camp J, personal communication).

### 6.2.4 Criterion-related validity of the Visual Score

The visual scoring system underwent more changes as is presented in Papers III and IV. Adaptations were made to make it usable for a total body surface evaluation rather than uncovered parts (face and hands) of a protected person as was originally presented in the US. We also took care of correcting the extent of exposure according to total BSA and a new indicator of exposure was presented, which is the Contaminated Body Area (CBA). The basic measure, the BSS, was tested against the amount of residues for the hands resulting in a correlation of 0.48 ($p=0.005$) for all and 0.76 ($p=0.000$) when excluding those who rinsed their hands (Paper V). Since intensity seemed to be the most subjective of the two components, correlation of fluorescent intensity levels were tested resulting in a correlation coefficient of 0.63, for both chlorpyrifos and methamidophos. The amounts of residues recovered from areas with different degrees of intensities were proportional to the fluorescence intensity gradient indicating satisfactory performance (Paper III). The signs of misclassification in the low contaminated areas were related to areas classified as low intensity that had non-detectable levels of pesticides, and areas classified as clean that had pesticide residues. Tests for sensitivity and specificity resulted in 54% and 71% respectively, reflecting the difficulties of identifying low contamination. This must also be partially due to the fact that the pesticide

**Table 5**. Performance of three exposure assessment methods

| **GENERAL TARGET** | **Evaluate current exposure** | | |
|---|---|---|---|
| | **Hygienic evaluation with video recording (CCI+SCI)** | **Fluorescent tracer visualization and visual score** | **Skin wipes on the hands and fluorescent areas** |
| Standardization from previous evaluations | No standardization several proposals | Based on Fenske (1988). Additions made that needed validation | Different methods, problems in comparability (Brouwer et al., 2000) |
| **Validity** | | | |
| Protocol Operational manual | Yes | Yes | Yes |
| Guidelines and instructions | Yes | Yes | Yes |
| Pre-Testing | Yes | Yes | Yes |
| Training | Yes | Yes | Yes |
| Pilot study | Yes | Yes | Yes |
| **Reliability** | | | |
| Internal consistency | Yes (Pilot) | Reliability study Cronbach alpha 0.96 | No |
| Reproducibility | Not evaluated | Reliability study ICC=0.75 | Not evaluated |
| Blinding of analyst | NA | NA | Yes |
| SCORING AND SCALES | Numeral scaling (# of contacts observed) and Ordinal scaling (direct and indirect contact) | Numeral scaling (0 to 25) and Ordinal scaling (low, moderate, high) | $\mu g/cm^2$ |
| Technical feasibility | Easy to apply. Only requires a form and video recording. | Easy to learn. Without visual score, Informative of contamination pattern | Needs several wipes |
| Social feasibility | Accepted by farmers | Accepted by farmers | Accepted by farmers |
| Cost-efficiency | Low cost | Low cost | High cost, may need repeated wipes |
| FACTORS INFLUENCING RESULTS | Observer presence | Observer training | Pesticide type interacting with the skin (lipohilic, hydrophilic). Number of times wiping. |

concentrate was not traced. The percentage of correct scoring for both low contamination and zero contamination in relation to the presence/absence of residues was 60% (test efficiency).

### 6.2.5 Reliability of the Visual Score

The reliability test performed showed that the system has a very high between-rater consistency (Cronbach alpha 0.90-0.96). The absolute values of the observers' ratings still differed with a factor of 2 on average. Inter-rater reliability coefficients were acceptable and indicated repeatability of the system. However, scoring of extent (ICC 0.80 [95%CI 0.71–0.86]) was more reliable than scoring of intensity (ICC 0.54 [95%CI 0.40–0.66]. The effect of subjectivity pertained mostly to the variability when scoring intensity was related to the quality of the images. Low agreement of the raters was associated to poor quality of the images particularly for reading low intensities.

### 6.2.6 Feasibility

The three methods are easy to apply, although assessment of the skin residues needs to be standardized, particularly the sampling procedure. Both the hygiene observation and the visual scoring system are of low cost since the analysis can be performed on site and the results can be revised with the videotapes and require short training. The skin wipe sampling procedures can be standardized although the analyses are expensive, and require long periods of training before starting the laboratory analyses. Table 5 summarizes the validity, reliability and feasibility aspects of each method.

## 6.3 Focus group interviews

A qualitative approach has the benefit of presenting the situation from the perspective of the workers, which represents an advantage when intervention studies are planned. With the interviews we could achieve a better understanding of how these farmers perceived their exposure to pesticides, and thus could extract and also contextualize their main exposure determinants.

From the results, it was clear that gaps in knowledge and economic constraints combined with cultural factors put the farmers in situations of no choice when using pesticides. The need for having "healthy" crops was a matter of their own survival in the sense of securing food for their families. The choice of using synthetic pesticides instead of natural pesticides or non-chemical alternatives for pest control, which they knew could be used, was the fastest response to the threat to their crops. The act of risking themselves cannot be seen as merely lack of training, but rather a combination of gaps in their knowledge concerning an important route of absorption, their need to find fast solutions to what is considered a threat to themselves and their families, the inability of existing PPE to protect them in a tropical climate, and availability of highly toxic pesticides with no restrictions in the local markets. The above confirms that "safe use" in a developing country is unfeasible (Murray & Taylor, 2001; Hruska & Corriols, 2002; Wesseling et al., 2005). For epidemiological and hygiene type studies, this information can be used for improvement of specific questionnaires and in the design of risk reduction strategies.

## 6.4 Integrating qualitative study and exposure evaluation

Qualitative data complement quantitative data. The combination of qualitative and quantitative results can be used in both ways. Either qualitative observations or interviews are the starting point, exploring areas for research or the statistical results are further explored or explained by qualitative methods. Table 6 shows results from Papers I and II and how hygienic observation corresponds to farmers´ views and how these views are related to the main exposure determinants, although the two papers concerned different populations of pesticide sprayers. As can be seen in Table 6, the strongest determinants in Paper II were the equipment used for spraying and gross contamination of the hands. These determinants are reflected in workers' view

**Table 6**. Comparison of results from the qualitative interviews, direct observation and main exposure determinants.

| Socioeconomic determinants | Qualitative interviews (Paper I) | Exposure Determinants Observation (Paper II) | Other sources |
|---|---|---|---|
| **Poverty** | Use of inferior equipment to spray pesticides<br>Inability to repair equipment<br><br>Not using proper clothing<br>Increased work pace when applying favoring heat stress | Spraying equipment<br><br>Gross contamination (leaking backpacks)<br>Clothing<br>Temperature<br>Dew on plants (Humidity) | 60% leaking backpacks<br><br>Table 4 |
| **Inadequate protective equipment** | Masks impossible to use in the hot climate<br><br>Boots were not used because they got stuck in the mud<br><br>Gloves uncomfortable | Temperature<br><br>Wet or slightly muddy terrain. | <br><br>Barefoot<br><br>Barehanded |
| **Knowledge** | Giving high importance to inhalation and ingestion (mechanisms of poisoning explained by them, pages 298-99) | Gross contamination of the hands by blocking a hose leakage, repairing nozzle or inserting hand into the tank. | Wide range of residues recovered from hands (0.01–6.23 μg/ /cm²). Paper V |

of their own exposure, which at the same time is connected with socioeconomic conditions of this group of farmers as well as cultural beliefs and traditions. Workers' perceptions of most important absorption routes (inhalation and ingestion) reflected the protective measures they used: a glass of milk to decrease toxicity of pesticide ingestion, and a wetted handkerchief to decrease inhalation exposure. The workers did not consider dermal exposure as a route of pesticide absorption, although farmers studied in Paper V frequently had direct and indirect contact with the pesticides (observed range of contacts 1 to 22 in one application session).

With this analysis we confirm that the uses of qualitative, semi-quantitative and quantitative methods to evaluate dermal exposure are complementary and that qualitative data help to contextualize quantitative data. We thus demonstrated by triangulation the benefits of combining different methods for the evaluation of one outcome (Mergler, 1999). Triangulation enhances the credibility of qualitative methods (Patton, 2002) and validity of quantitative methods (Armstrong et al., 1992).

## 6.5 Exposure determinants

Knowledge of factors associated with exposure levels is essential for the design of efficient risk reduction strategies. Identification of determinants is also important in defining the subsets of workforce that are particularly vulnerable to health hazards (Burstyn & Teschke, 1999). The identified exposure determinants among Nicaraguan subsistence farmers revealed important hygiene issues that can be applied to pesticide sprayers in developing countries. An added value of the study has been the identification of new determinants of exposure in this type of work. The criterion variable for identification of determinants has usually been based on air sampling measurements and questionnaire applications. The sampling strategies have mostly been related to inhalation route (Burstyn & Teschke, 1999). Few studies have evaluated determinants of dermal exposure. Some used pad samplers or patches for the exposure assessment (Vermeulen et al., 2001; Prince et al., 2001) and one used VITAE quantifying exposure using a fluorescent tracer (van Wendel de Joode et al., 2005b).

We used the total visual scores resulting from the videotaped fluorescence observed on the skin that showed that such contact occurred. The scores not only indicate the body areas that were contaminated by pesticides but also the extent of the contamination of body segments and the whole body surface. This enabled the identification of the factors that contributed to high contamination of the hands, the legs and instep of the feet, the spraying being done barehanded and barefoot.

Paper II argues that fluorescent images reflect patterns of contamination rather than true pesticide exposure since the concentration of the tracer in the solution does not reflect the concentration of the active pesticidal ingredient. For risk reduction strategies the identification of the exact amount of a chemical that is deposited on the skin is not as relevant as the recognition of the extent of skin contact with the pesticide. For epidemiological studies, the concentration of the pesticide formulation could be included in the exposure score as an additional factor. However, additional validation should then be performed.

Leaking of the tank of the backpack did not emerge as a major exposure determinant, which we had expected (van Wendel de Joode et al., 1996). A possible explanation is that the exclusion of the buttocks and genitalia influenced the results. The TVS used in Paper II did not consider the size of each body area contributing to total dermal exposure. After correcting for area (Paper III), the back resulted with the highest BSS as an average. There is a possibility that with the adjusted TVS, the leaking tanks could appear as one of the exposure determinants. Considering the advantage of observing the extent of exposure with the fluorescence after the farmer has been exposed, i.e. CBA, this method seems to be the best tool for the identification of dermal exposure determinants.

## 6.6 General assessment of the methods

The three methods tested in this study have their strengths and limitations. Improvements can be made, as summarized below.

### 6.6.1 Strengths

Contamination indexes are essentially observational tools which can be enhanced with the use of videotapes. An advantage with this method is that it only requires observation of current exposure and a video camera. The frequency of hand contact is a highly important determinant of exposure in backpack spraying. The frequency differentiates distinct degrees of exposure. In addition, the method is cheap, appears to be sufficiently reliable and does not need lengthy training periods. Additionally, the description of contact events provides insight into hygienic behavior and possibilities for intervention, such as creating awareness of the fact that backpack and cloth surfaces are frequently contaminated and therefore hands get contaminated by either transfer or redistribution from these surfaces (Schneider et al., 1999).

The qualitative use of the fluorescent tracer and the semi-quantitative "Visual Scoring System" with its modifications are examples of dermal exposure evaluation under developing country conditions. The feasibility and reliability of the method have been evaluated under real-life circumstances which are important considering that methodological studies are frequently performed in a quasi-experimental way leading to bias since they tend to reduce exposure variability (Teschke et al., 1994). With improvements for intensity scoring, this method can be applied in developing countries. Although the study did not aim at finding exposure pathways through the fluorescent tracer visualization, contamination patterns indicated possible sources of exposure, i.e. the low proportion of upper right arm contamination linked to the location of the hose of motorized backpacks at the waist level, and the contamination of the back linked to a badly sealed lid plus an overfilled tank, as presented in Paper III. In addition, fluorescent patterns allow the farmers to observe themselves the contamination and its distribution on the skin, creating awareness of their factual contact with the pesticide.

The "extent" component of the Visual Score differentiated degrees of skin exposure through proportion of skin contamination. A very low level of 1% corresponded to a farmer who used a motorized backpack, took into account the wind direction, had a helper to mix the pesticide in the tank, wore long trousers and a long sleeved shirt, and sprayed for a short time. The highest extent of 66% corresponded to a farmer who used a manual backpack, sprayed towards the front, regulated the flux of the nozzle constantly with his bare hands, wore shorts and a sleeveless t-shirt, and sprayed for more than one hour.

Skin wipes were easy to implement in the field, which in contrast with hand wash do not require carrying large volumes of solvents, only the use of a few gauze pads wetted in isopropanol (Geno et al, 1996). The best and simplest advantage of skin wipes is the demonstration of presence or absence of pesticide deposition regardless the amount recovered. The method helped to confirm that none of the farmers escaped skin contact with the pesticide and also revealed a wide range of residues on the hands of these farmers, from 0.01 to 6 $\mu g/cm^2$, thus showing a large variability of exposure among these farmers. With repeated measurements, skin wipes together with the visual scoring system can assess the within-worker variability (Kromhout et al., 2004).

One interesting finding was that chlorpyrifos residues were on average more than twice as high as methamidophos residues (Paper V), suggesting different pesticide-skin interactions between the lipophilic chlorpyrifos (Griffin et al., 1999; Griffin et al., 2000) and the hydrophilic methamidophos. Nicaraguan farmers usually combine two or more pesticides to increase effectiveness. In fact, four of the farmers combined the two selected pesticides. Although they used almost the same initial concentration of methamidophos and chlorpyrifos, the amount of chlorpyrifos recovered from the hands was double as compared to methamidophos. Although chlorpyrifos has been thoroughly studied (Griffin et al., 2000; Meuling et al., 2005), the interaction and absorption of methamidophos through the skin needs further study.

Table 7 summarizes current and potential use of the three methods. Observational contamination indices and fluorescent tracers provide information about sources and extent of dermal exposure while the skin wipes inform about skin loading and can give clues about possible pesticide skin interaction. The three methods can also differentiate high from low exposure. Combining the three methods and using the qualitative information, we can

**Table 7**. Aims and intended measurement of the three methods:
BSS: Body Segment.CBA:Contaminated Body Area. TVS: Total Visual Score.

| **Method** | **Objective** | **Capable to assess** | **Does not assess** | **Potentially capable to assess** | **Possible bias** |
|---|---|---|---|---|---|
| **Contamination indexes for the hands** | Evaluation of number of contacts of the hands with the pesticides directly or through contaminated surfaces | Frequency of contacts<br><br>Differentiate direct and indirect contact<br><br>Differentiate high from low exposure | Time of exposure<br><br>Exposure loading<br><br>Uptake | Identification of main sources of exposure<br><br>Differentiation between direct and indirect exposure<br><br>Guides hygiene control strategies | Observer presence could change farmer's practices. |
| **Visual Score/ Fluorescent tracer** | Evaluation of contaminated patterns, extent and intensity of dermal exposure | Skin contamination<br><br>Exposure patterns and pathways<br><br>Dermal exposure distribution and extent: BSS, CBA and TVS<br><br>Differentiate high and low exposure | Exposure loading ($g/cm^2$)<br><br>Uptake | Exposure surface ($cm^2$)<br><br>Dermal exposure to other substances<br><br>Differentiates between direct and indirect contact combined with the conceptual model (Schneider et al., 1999) | Quenching and/or degradation of the fluorescent tracer on the skin with long exposure time. |
| **Residues/ skin wipes** | Estimation of skin loading at the time of sampling | Exposure mass at the time of sampling (g)<br><br>Exposure loading at the time of sampling ($g/cm^2$)<br><br>Differentiate high and low exposure | Extent of dermal contamination<br><br>Uninformative of exposure pathways<br><br>Uptake | Clues of possible pesticide-skin interaction especially for those farmers that mix at least two pesticides | Lack of standardization of sampling strategies could affect the recovery efficiency and underestimate the skin loading |

make available a more comprehensive picture of dermal exposure and establish more adequate strategies to reduce exposure.

### 6.6.2 Limitations

Limitations of contamination indeces as observational tools are related to bias both due to the ability of the observer to capture all the events and the observed person that can change his/her behavior due to the presence of the observer.

The first limitation can be overcome with the use of videotapes (that open the possibility of revising the events), and the second one can be reduced by creating a confident environment between the observer and the observed person.

In relation to the fluorscent tracer, an important limitation as a qualitative tool as well as of the semi-quantitative visual scoring system is that it is not informative of skin loading. Although the original intent of the visual scoring system was to represent pesticide loading (Fenske, 1988b), the test does not always perform as a real tracer of the pesticide (Fenske, 2005). The high variability coming from the physico-chemical properties of the pesticides and their interaction with the skin makes it difficult to find standardized ways of assessing such exposure.

Another limitation is that, since the tracer is added only to the pesticide solution, the contamination with pesticide concentrate cannot be traced. The fluorescent tracer also fails to record repeated exposure if the skin has already reached its maximal capacity of tracer deposition.

There are still difficulties in assessing low contamination, which was reflected by the low level of agreement to classify intensity among raters. Sources of discrepancies in the reading were also associated with poor quality of the image. Both factors are related. There were difficulties to film some body surface segments with low or no fluorescence in a dark room, which seems to be inherent to the method and probably suggests that missing data correspond in fact to zero or very low scores. Although the raters considered the image characterization a useful tool for scoring, their judgment did not always agree regarding low contamination areas. This could have been the result of a too short training time or the subjective element in the method.

The quantitative method also had its limitations. It has the highest cost of the three methods and the sampling strategy needs to be revised, since the number of wipes with a single gauze-pad does not seem to guarantee a good recovery efficiency, and can also be influenced by the solvent used (Campbell et al., 2000; Brouwer et al., 2000). Additionally, the skin wiping only represents the amount of pesticide present on the skin surface at the moment of sampling (Brouwer et al., 2000). It does not assess the entire pesticide quantity that reaches the skin during the application process, because of absorption and evaporation. Another limitation is that no insight is provided into the mechanisms according to which exposure occurs and removal efficiency decreases with decreased skin loading (Fenske, 2005).

Table 7 summarizes limitations for each method and possible bias. The main limitation of the three methods is that none of them can estimate dermal uptake, which is important due to potential systemic and dermal health effects. Despite this limitation, the strengths and possibilities that the three methods offer are informative enough to avoid or reduce dermal uptake and therefore prevent adverse health effects.

### 6.6.3 Improvements

The design of the foldaway dark room has to be further elaborated through engineering techniques in order to reduce filming time, aiming at increased space, tolerable ambient temperature and proper illumination. To obtain a well-focused image during the videotaping, the camera should be fixed for several seconds on the body part. Also further improving the videotaping technique with methods to stabilize the hand-held camera and achieve steady focus at specified distance from the skin, as well as the use of filters for the video camera and for the source of the UV illumination can contribute to better quality of the images. Training should emphasize the reading of low contamination parts and the inclusion of illustrations for this purpose can enhance the scoring guide. Concerning the skin wipes, sampling parameters such as the number of wipes or the number of gauze-pads as well as the sampling strategy needs to be improved through sampling efficiency tests performed previous to data collection as feasibility trials (Brouwer et al., 2000).

## 6.7 Summary

The present studies showed that subsistence farmers, during application, were heavily exposed to pesticides in body areas such the hands, back, feet and legs in that order. The exposure was related to the type of pesticide, formulation used, concentration, shape of the equipment, environmental conditions, clothing, and hygienic behavior. The reasons for the heavy exposure were related to economic constraints, limited knowledge influenced by beliefs and traditions, inadequacy of protective equipment, and weak regulations. The dermal route is an extremely significant route among Nicaraguan farmers since they are usually unprotected and because of climate. They therefore cannot use the available PPE nor afford to buy them. On the other hand, risk assessment strategies developed in industrialized countries do not seem to be applicable to these farmers. It is therefore necessary to test and adapt the methods based on the poor-country scenario. As an example, chemical analyses for the present study were very expensive, therefore it cannot be expected to have them available for routine risk assessment procedures in the country. Nevertheless, it is of extreme importance that methods and models to evaluate exposure to toxic substances in countries like Nicaragua are applied. There are other possibilities for using the fluorescent tracer; one way is as a tool for a systematic description of the different pathways of exposure based on the conceptual model presented by Schneider et al. (1999). Therefore, while more research is being done into the performance of models in relation to actual (human) dermal absorption for a wide variety of chemicals, we should take advantage of the benefit of using available, reliable, and already adapted methods to evaluate exposure among this type of farmers. With further improvements, the adapted visual scoring system and the contamination indexes are now available for risk assessment, education, and intervention. They may also to be included or tested with other already established semi-quantitative methods such as the DeRmal Exposure Assessment Method (DREAM) (van Wendel de Joode et al., 2003). Future studies should include family members for the assessment of exposure and its determinants. Biological monitoring would add to validity.

# 7 Conclusions

- The qualitative, semi-quantitative and quantitative evaluations corroborated a high level of dermal exposure to pesticides among the farmers.

- Data on exposure determinants and frequencies of body segments contaminated can be used for the construction of job-specific questionnaires for hygiene evaluations, epidemiological studies, and for designing training programs.

- A combination of observations and fluorescent tracer visualization and scoring can provide valuable information on determinants of pesticide exposure, while quantitative methods will confirm the presence of the contaminant.

- Both observation and fluorescent tracer technique are low-cost and feasible for developing countries.

- Qualitative data on farmers' beliefs and perceptions enhance improvement of higher-quality specific questionnaires and efficient risk reduction strategies.

- For intervention purposes, dermal exposure methods are preferable in combination with qualitative studies.

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