Three Methods to Assess Levels of Farmers' Exposure to Pesticides in the Urban and Peri-urban Areas of Northern Benin

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ABSTRACT

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Small farmers in urban and peri-urban areas of Northern Benin use pesticides without respect of hygiene rules and any personal protective equipment (PPE). Based on observation of the local practices in Djougou, Gogounou and Parakou,field trials have been carried out under similar conditions to evaluate contamination and exposure levels of farmers, using three usual sampling methods (Visual Method, Patch Method and Whole Body Method). Both Visual and Patch Methods used dye and ghost ink as tracers. In the Whole Body trials, deltamethrin (PLAN D 25 EC) was used as insecticide treatment. Deposits were observed on the protective equipment and on the collectors. Tartrazine was determined by colorimetry and deltamethrin by gas chromatography with ECD detector (GC-ECD). The examination of protective equipment (Visual Method) showed that the whole body could be potentially exposed to pesticides. Hands were contaminated during the preparation and the loading of mixture up to sprayer rinsing. The Patch Method was not perfectly able to predict the contamination pattern on the farmers' body. The Whole Body Method results appeared to be more variable and influenced by the skill of each operator compared to the Patch Method. The contamination levels observed were rather higher than the value estimated with a theoretical model (from 368 to 2867 mg of deltamethrin at the total/body). With PPE, the average exposure reached 3.25 mg/kg bw/day. Without PPE, the potential exposure was equal to 32.52 mg/kg bw/day. Both values far exceed the AOEL of deltamethrin (0.0075 mg/kg bw/day) indicating a high risk level for the operator. The theoretical used model (UK-POEM) was unable to predict the potential exposure outcomes measured in these trials.

Keywords: Backpack sprayers, exposure assessment, pesticides, small scale growers

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In Benin, horticulture is today one of the main components of urban and suburban agriculture. It represents an important source of incomes for thousands of small producers, mainly aged between 21 and 40 years old (Adorgloh 2006; Allagbé et al. 2014). On the tomato strategic speculation for urban producers, there are no fewer than 37 pests (Chougourou et al. 2012). Face to this threat, farmers use intensively broad spectrum insecticides. Pyrethroids (54% of applications) are often associated with organophosphorus insecticides (25% of applications) (Ahouangninou et al.

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2011; Azandémè-Hounmalon et al. 2014). These chemicals can significantly improve yields, as demonstrated by Cissé et al. (2003) in Senegal, but lack of information on routes of exposure, pesticide toxicity, small resources and intensive use of pesticides lead to a significant contamination of the environment (soil and water) with the destruction of beneficial insects (Deguine and Ferron 2006) in addition to the high exposure of small producer.

During treatment, dermal and inhalation exposure are the main routes of exposure (EFSA 2010; Fenske and Elkner 1990; Kim et al. 2013). Farmers' exposure to pesticides while using backpack sprayers mainly occurs through the dermal route (Machera 2003). The risk of detrimental health effects should be significant for small producers in Northern Benin due to frequent treatments with very toxic and highly concentrated pesticides registered to control resistant cotton pests (Assogba-Komlan et al. 2007).

Moreover, it is known that pesticides are often handled and applied by many operators without hygiene rules or proper personal protective equipment (PPE) (Godeaux et al. 2008; Stimamiglio et al. 1998). Nevertheless, few studies have been dedicated to estimate the potential exposition of the small scale growers when handling insecticides and spraying in situ, with their usual practices and their own backpack sprayers. To assess the risk of exposure in field conditions, a study was undertaken in the outskirts of major cities of Northern Benin (Djougou, Gogounou, and Parakou) in order to identify the most exposed body parts and to characterize the potential levels of exposure.

Exposure to pesticides during field applications can be estimated by measuring the contamination of the skin (Syamimi et al. 2011). To evaluate the distribution of mixture droplets on the body, three methods are currently used (Salyani and Whitney 1988; Tannahill et al. 1996), known as Visual sampling Method, Patch sampling Method and Whole Body sampling Method.

The "Visual sampling Method" consists to mix a dye, an ink or a fluorescent product with water in the spray tank to form a mixture to have after spraying a global view of the distribution pattern of deposits on the whole body (results are only qualitative but indicative). Tartrazine was used by many authors (Koch et al. 2006; Pergher and Lacovig 2005) and the ghost ink by Ncamurwanko (2012).

The "Patch sampling Method" was described in the "*Guidance Document for the Conduct of Studies of Occupational Exposure to Pesticides During Agricultural Application"* (OECD 1997). Collectors (patches) are placed on various body parts to collect during spraying the droplets of mixture with a dye dispersed to the water tank. At the end of work, deposits on the collectors are measured, reported and extrapolated to the surface of the exposed body part. This may be done using standard surface area of body parts such as those proposed by WHO (in 1982), by EPA (in 1987) or, more recently, by OECD (in 1997).

The "Whole Body sampling Method" (Chester 1993 1995; Gonzalez et al. 1999; WHO 1982) consists to dress an operator with a coverall that covers completely the body to serve as a global collector (imitating the "skin") and cutting it in several pieces after spraying to extract and analyze the pesticide deposits (Garrido Frenich et al. 2002; Syamimi et al. 2011).

Those methods, where tracers are used as substitution elements to pesticides, are simple, cheap and easy to implement without risk for operators during the trials. Therefore, many authors used tracers to evaluate the drift (Stainier 2006) or the potential contamination (Gil et al. 2005; Gil 2007; Kadri et al. 2012; Koch et al. 2003; Yates et al. 1976). However, the results obtained with this method can always be discussed, since the mixture of a tracer does not have the same physicochemical properties (density, viscosity and surface tension) than a mixture with a pesticide formulation and usually the tests with collectors are not performed in real field conditions and by farmers.

Therefore, it was interesting to compare results obtained with the Visual and Patch Methods (with mixtures containing tracers and tests performed by the research team) and results of the Whole Body Method (with a mixture of water and a plant protection product, and tests performed by farmers themselves) in order to check if Visual and Patch Methods could really be reliable to assess the distribution of pesticides on the body under field conditions. The conclusions of this study could help researchers who want to assess the performance of the Visual and Patch Methods compared to the Whole Body Method and, on the other hand, should enable risk managers to take certain measures and to issue appropriate recommendations of personal protection tailored to local economic context.

Furthermore, when measuring insecticide deposits on the body, it should be possible to estimate if the risk level could be considered as acceptable for the small producers according to their usual practices. The risk will be considered as acceptable if the potential exposure (measured on the patches or obtained using an exposure model such as UK-POEM) is lower than the AOEL value (*Acceptable Operator Exposure Level*, expressed in mg as/kg bw/day) (EFSA 2014).

MATERIALS AND METHODS

Study sites.

A careful observation of local growers practices and field trials have been carried out on the outskirts of three large communities of Northern Benin (Djougou, Gogounou, and Parakou). The sites on which the field trials were conducted have similar characteristics: a high population growth (from 3.45% for Djougouup to 4.81% for Parakou) (INSAE 2013), a sustained demand for vegetables and, consequently, a permanent increase of urban and suburban production areas with an intensive use of pesticides. These sites are cultivated since the 80’s by growers originating from Cotonou (Allagbé et al. 2014) on very small surfaces with vegetables (tomato is the main crop) grown in the dry and rainy seasons (Adékambi and Adégbola 2008). In Djougou area, the presence of several rivers and valleys are favorable to horticulture which is a very ancient activity with different cropping systems (Simeni et al. 2009). This city is an important crossroads and its frontier markets with Togo constituting an easy outlet for the main local productions. In Parakou and Gogounou, vegetable production areas are concentrated around water points (wells and streams, finished or unfinished). Enforcement practices selected for field trials have been based on observations made in these three sites which were representative of how farmers usually work in Benin when they apply plant protection products on their crops with backpack sprayers.

Methods used to estimate the contamination of the operator’s body.

Three different sampling techniques have been implemented successively in this study to assess the exposure of operators' body: Visual, Patch and Whole Body Methods. According to literature, each method alone cannot be sufficient for a reliable evaluation of operators' exposure but their combination should provide a rather good representation of the contamination during application in Benin.

All sprayings were performed with backpack sprayers (flat fan nozzle, about 700 l/ha) by local right-handed voluntary operators or farmers with a walking direction perpendicular to the dominant wind. Farmers were asked to work according to their usual practices, as previously observed. During the field trials, all of them have worn white coveralls (TYVEK type or cotton type for the whole body trials) with a hood, boots, gloves resistant to chemicals and a filter mask. All tests were conducted on 800 m² plots.

An average temperature of 33.5°C and relative humidity of 61.4% were recorded during the field trials using a thermo-hygrometer (TFA, Kat. N°30. 5007). The average wind speed measured during the tests with an anemometer (HMI CFM/CMM SI 6190) was 2.3 m/sec (1.7-3.1 m/sec).

- *The Visual Method*

A dye or a ghost ink was added separately to water tank to obtain spraying mixtures. Tartrazine (E102 code, an azo compound yellow) is a non-toxic food grade coloring (Acros Organics, 89% purity). Added to water (10 g/l), it allows a good visualization of the cover on a white combination (Murray et al. 2000). The ghost ink (110 NORIS UV) is a non-toxic liquid detectable and visible under UV light frequently used for demonstrations during training (Shiffers and Mar 2011). After mixture applications, operators' body were put under visible light (tartrazine) or black light (UV lamp for ghost ink) to take pictures of their coverall and hands, and to view the contaminated parts and equipment (e.g. gloves and boots). Various tests were performed both without vegetables and in chili fields at different working heights (Loquet et al. 2008).

- *The Patch Method*

The number and the distribution of patches were adapted from the WHO Standard Protocol (1982) and OECD guidelines (1997) as described by Kadri et al. (2012). In this study, the tartrazine dye (Acros Organics, 89% purity) was preferred due to its non-toxicity, friendly to use, both easy to extract from collectors and to measure by colorimetry with good sensitivity and linearity of absorbance values. Tartrazine was mixed to the water tank (10 g/l). Two trials were carried out by operators belonging to the research team using a backpack sprayer, at two different heights (0.5 and 1 m). The patches (or collectors) were square pieces of 100 cm² in unbleached cotton spread all over the farmers' body and firmly attached to the coverall (TYVEK type protection suit) to collect the droplets of mixture. After spraying, all collectors were removed from the coverall, transferred to a FALCON® tube to which is added 30 ml of distilled water for extraction and the absorbance was immediately measured with a Macherey-Nagel colorimeter (Nanocolor 500D) at $\lambda = 436$ nm. Concentration in the extract was then determined according to a calibration curve ($y = 0.0544\,x$; $r^2 = 0.9994$) previously established with 8 concentrations of dye (from 0.17 to 21.80 µg/ml, to reach a maximum absorbance of about 1 unit). The absorbance of blancos (white cotton pieces in 30 ml of distilled water) was previously measured and considered negligible. Results were reported in mg/cm² and extrapolated to the body part on which the patch was fixed using the table giving the average area of each part of the body as proposed by the OECD guidelines (results are therefore semi-quantitative).

- *The Whole Body Method*

For this trial, applications of a mixture (insecticide PLAN 25 EC dispersed in water) were performed by three voluntary farmers wearing new unbleached cotton coverall. The duration of work was fixed at fifty minutes after what the coveralls were collected and left to dry in the shade as recommended by Machera et al. (2003). To limit the number of analyses, the coveralls were cut into 5 big pieces according to Fig. 1 and adapted from Garrido Frenich et al. (2002) for analysis: sleeves (shoulder-arm) left and right, thorax (chest and back), legs (thigh and tibia) left and right. The deposits and distribution of PLAN 25 EC (deltamethrin) on the entire body was extracted and determined by gas chromatography. None interference was detected in extracts of blancos (unbleached cotton pieces).

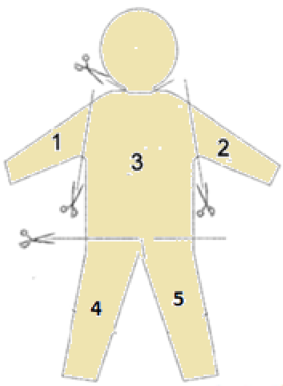

Fig. 1. Cutting of the combination into 5 parts, adapted from Garrido Frenich et al. (2002) (1: right sleeve; 2: left sleeve; 3: thorax (chest and back); 4: right leg; 5: left leg).

Insecticide choice.

PLAN 25 EC is an emulsifiable concentrate packaged in bottles of 250 ml containing 25 g deltamethrin/l, and the best seller insecticide in Benin. Deltamethrin is a contact insecticide. It is a pyrethroidtoxic chemical (oral LD_{50}: 87 mg/kg bw; dermal LD_{50} > 2000 mg/kg bw; ADI 0.01 mg/kg bw/day). The value of the systemic AOEL has been set to 0.0075 mg/kg bw/day (EU Pesticides Database, 2016). Moreover, deltamethrin was also considered particularly suitable for testing because it is very stable (air, light and temperature), does not adsorb textiles irreversibly (it is used for mosquito netting), and is soluble in many organic solvents. Deltamethrin, both easily adsorbed on patches and extracted, is therefore very suitable for this test. Finally, it can be dosed even at low concentrations by gas chromatography (GC). The analytical method was previously validated internally to be used in routine tests (LOQ ≤ 0.01 mg/kg).

Extraction and dosage of deltamethrin extracted from the coverall.

Having determined the mass per cm² (either 13.14 mg/cm²) and the weight of each part of the coverall, their surface were determined accurately. After weighing, they were torn into small pieces using scissors and about 15 g of cut tissue (or 1141.55 cm²) are taken at random and transferred into an Erlenmeyer flask to which 200 ml of dichloromethane (stabilized with approximately 50 mg 2-methyl2-butene/l) were added for extraction for 24 hours. After stirring, the solution is transferred into a ground ball by filtering it on pleated paper. The Erlenmeyer flask is rinsed again with another 100 ml of dichloromethane. Solutions were stored in a refrigerator at 4°C before analysis. The filtrates were dried-out using a rotary evaporator and finally residues were dissolved in 2 ml of trimethyl (or higher volume when dilution is needed). The analysis of deltamethrin was performed by gas chromatography (GC) with an Electron Capture Detector (ECD, constant current), in splitless (at 280°C), by injecting 1 µl on an Optima column (5-30 m × 0.25 mm - 0.25 µm) with a program of temperature (1 min at 90°C; 10°C/min to 320°C for 5 min) and the ECD detector (Ar/CH_4, 1.7 kg/cm², pulse amplitude = 50 V, pulse delay = 1 µs, pulse width = 0.1 µs and reference current = 0.5 nA) at 290°C. Deltamethrin concentration was determined according to a calibration curve established from 0.1 to 2 µg/ml ($y = 2.4203 + 1.3968\, x$; $r^2 = 0.9831$).

Risk assessment using an exposure model.

Potential exposure values can be predicted using various theoretical models (EFSA 2014). The English model UK-POEM (*Predictive Operator Exposure Model*) was selected because this model helps to simply calculate potential exposure for operators using backpack sprayers (hand-held sprayers). This is the only POEM where hand-held sprayers are considered. As the working scenarios can differ from Europe, results will be analyzed with caution and will be only indicative. The model is an Excel® spreadsheet, in which some parameters are introduced and others are set by default (e.g. surface treated, work duration, skin absorption), providing the potential exposure value of an operator (mg as/kg bw/day). Based on this theoretical model, potential exposures were calculated for various working conditions (e.g. with or without protective equipment) and compared not only to the AOEL value of deltamethrin but also to the results of analysis of the coverall.

RESULTS

Distribution of the deposits observed with the Visual Method.

Examination of the gloves and the coverall under visible or UV light allowed visualization of the location of tartrazine deposits or ghost ink spots at the end of the tests. Observations showed that different body parts have been exposed to pesticides, but to varying degrees. As expected, the hands of operators (inside and outside the gloves) have been contaminated (Photo 1) during opening the package and rinsing of the sprayer. The back which supports the sprayer (and the thorax in general) was not spared from contamination, and deposits' spots were visible on 50% of the back surface. Nevertheless, observations indicated that thelower legs have been heavily exposed during spraying (Photos 2 and 3). The contamination appeared clearly more distributed on the bottom, below the knees. In tests carried out in chili fields where plant height was greater than 1 m, tartrazine or ghost ink were distributed up to the thighs (Photo 3) or almost to the middle of the body.

Photo 1. Operator contaminated hands (ghost ink).

Photo 2. Contaminated lower limbs (ghost ink).

Photo 3. Coloration of the coverall (legs covered by tartrazine).

Distribution of the deposits observed with the Patch Method.

Tables 1 and 2 show the results for the average quantities of tartrazine measured on 11 collectors in two trials with a backpack sprayer, for two heights (0.5 m and 1 m). Theoretical distribution was obtained by extrapolating the deposits/cm² to the body surface using the OECD table (1997). Total quantities collected and distributions on the body were remarkably close between the two repetitions, indicating a good reproducibility of this method. All parts of the body were contaminated (even head and face), but the greater part of the contamination was located on the legs (thighs and tibias). Chest and back (thorax) did not appear heavily contaminated in results obtained with the Patch Method.

Table 1. Quantities of tartrazine measured on the collectors and distribution of deposits on various body parts when applying the mixture with a backpack sprayer at 0.5 m height (conventional surfaces of the body parts are given in the OECD table)

Body part (collector)	Test 1 (µg/cm²)	Test 2 (µg/cm²)	Average (µg/cm²)	Surface (cm²)	Average deposit (µg)	Total distribution (%)
Head and face	0.188	0.193	0.190	1300	247.33 ± 5.07	1.32 ± 0.03
Neck	0.590	0.595	0.593	260	154.05 ± 0.92	0.82 ± 0.00
Shoulder-right arm	0.369	0.398	0.384	2910	1115.99 ± 59.67	5.94 ± 0.32
Right forearm	0.188	0.176	0.182	1210	220.20 ± 9.44	1.17 ± 0.05
Shoulder-left arm	0.535	0.535	0.535	2910	1556.85 ± 0.00	8.29 ± 0.00
Left forearm	0.210	0.210	0.210	1210	253.57 ± 0.00	1.35 ± 0.00
Thorax	0.320	0.320	0.320	3550	1135.48 ± 0.00	6.04 ± 0.00
Right thigh	1.307	1.307	1.307	3820	4992.68 ± 0.00	26.58 ± 0.00
Right tibia	1.903	1.903	1.903	2380	4528.13 ± 0.00	24.10 ± 0.00
Left thigh	0.585	0.585	0.585	3820	2233.01 ± 0.00	11.89 ± 0.00
Left tibia	0.982	0.993	0.987	2380	2349.38 ± 18.56	12.51 ± 0.10
Total	-	-	7.194	-	18786.66	100.00

Table 2. Quantities of tartrazine measured on the collectors and distribution of deposits on various body parts when applying the mixture with a backpack sprayer at 1 m height (conventional surfaces of the body parts are given in the OECD table)

Body part (collector)	Test 1 (µg/cm²)	Test 2 (µg/cm²)	Average (µg/cm²)	Surface (cm²)	Average deposit (µg)	Total distribution (%)
Head and face	0.392	0.408	0.400	1300	520.00 ± 14.71	3.16 ± 0.09
Neck	0.866	0.850	0.858	260	223.08 ± 2.94	1.36 ± 0.02
Shoulder-right arm	0.755	0.755	0.755	2910	2197.05 ± 0.00	13.36 ± 0.00
Right forearm	0.358	0.689	0.524	1210	633.44 ± 283.20	3.85 ± 1.72
Shoulder-left arm	0.397	0.667	0.532	2910	1548.12 ± 555.57	9.41 ± 3.38
Left forearm	0.369	0.369	0.369	1210	446.49 ± 0.00	2.71 ± 0.00
Thorax	0.425	0.424	0.425	3550	1506.98 ± 2.51	9.16 ± 0.02
Right thigh	1.048	1.408	1.228	3820	4690.96 ± 972.41	28.52 ± 5.91
Right tibia	0.540	0.540	0.540	2380	1285.20 ± 0.00	7.81 ± 0.00
Left thigh	0.474	0.474	0.474	3820	1810.68 ± 0.00	11.01 ± 0.00
Left tibia	0.667	0.667	0.667	2380	1587.46 ± 0.00	9.65 ± 0.00
Total	-	-	6.771	-	16449.45	100.00

Fig. 2 compares the distribution of the mixture on the body when the treatment is performed at low height (0.5 m, as at the beginning of the crop) or at medium height (1 m when the plants have grown). It was observed that a larger portion of the mixture had contaminated the upper body when the working height increases, especially on the right side of the hose (all tests performed by right-handed operators).

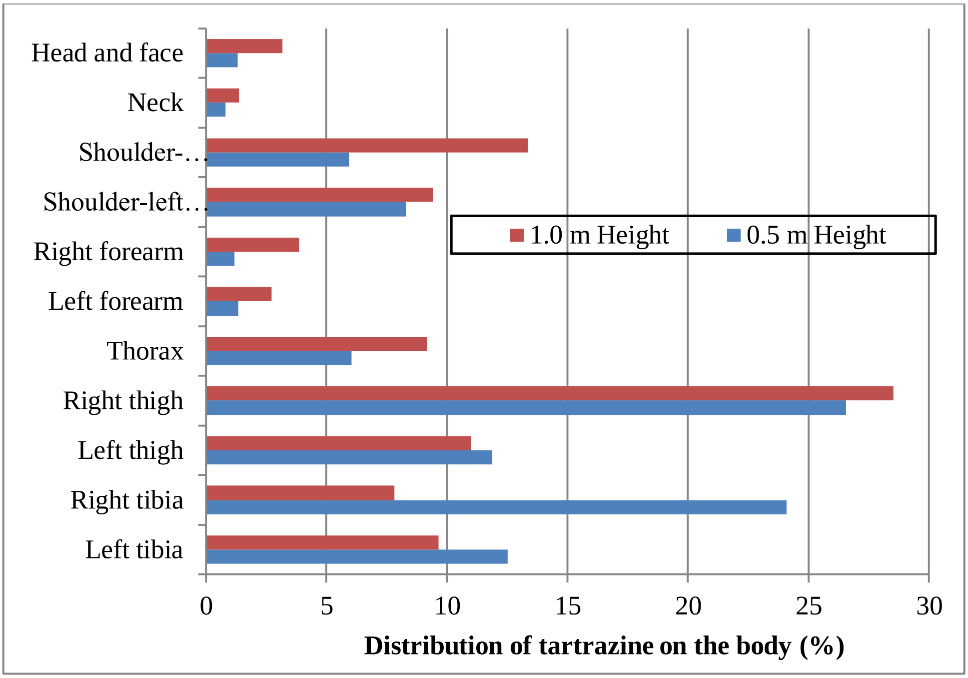

Fig. 2. Distribution of tartrazine on various parts of the operator's body for two heights (0.5 and 1 m) with a backpack sprayer in controlled conditions.

Distribution of the deposits observed with the Whole Body Method.

Table 3 outlines the results relating to the quantities of deltamethrin measured on each side of the coverall cut in 5 pieces. Tests were performed by three farmers in their fields and with their own practices and equipment.

Fig. 3 compares the distribution of deltamethrin on 5 parts of the body according to three different farmers working in their field, with their own practices and equipment.

From Table 3 and Fig. 3, it appeared clearly that thorax (chest and back) and legs were the most contaminated parts of the body during spraying in field conditions.

Table 3. Deltamethrin distribution on each part of the coverall of four operators (values of deposits/cm² for a sample substantially equal to 15 g, surface of each cut piece and total amount of deltamethrin on each part)

Operator and combination	Cut portion of the coverall	Surface of each piece (cm²)	Deltamethrin (µg/cm²)	Deltamethrin on each part (mg)	Distribution on each body parts (%)
Farmer No. 1	Shoulder-right arm	2058	2.690	5.54	0.2
	Shoulder-left arm	1904	1.200	2.28	0.1
	Right leg	8105	125.540	1017.50	35.4
	Left leg	7846	107.650	844.65	29.5
	Thorax (chest & back)	9810	101.630	996.96	34.8
	Total quantity			2866.94	100%
Farmer No. 2	Shoulder-right arm	1729	0.590	1.02	0.3
	Shoulder-left arm	1684	1.650	2.78	0.7
	Right leg	7511	8.070	60.62	16.5
	Left leg	7367	6.5600	48.33	13.1
	Thorax (chest & back)	12580	20.320	255.62	69.4
	Total quantity			368.37	100%
Farmer No. 3	Shoulder-right arm	1689	28.350	47.90	1.8
	Shoulder-left arm	1825	5.450	9.95	0.4
	Right leg	7755	70.310	545.25	20.8
	Left leg	7953	49.160	390.96	14.9
	Thorax (chest & back)	13280	122.380	1625.21	62.0
	Total quantity			2619.27	100%

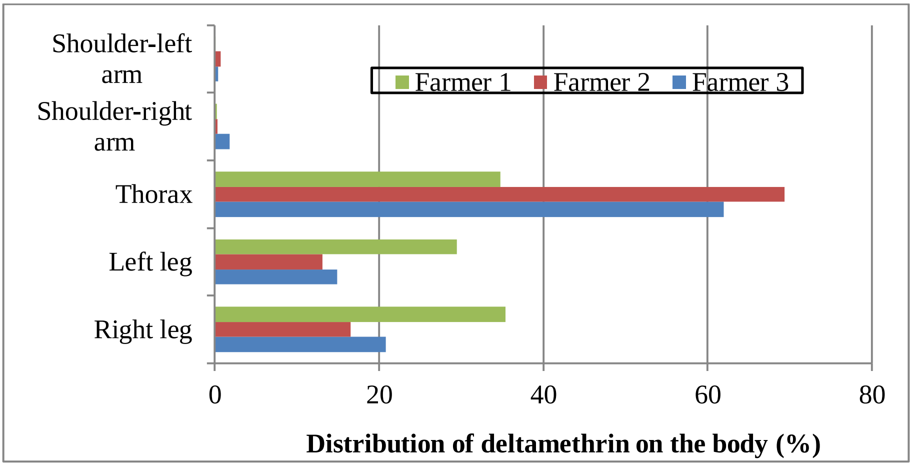

Fig. 3. Deltamethrin distribution on the various body parts of three farmers after spraying with a backpack sprayer in field conditions.

Estimate of the exposure level of operators according to the UK POEM model.

The UK-POEM model was selected for the insecticide PLAN 25 EC. The parameters entered in the calculation model are listed in Table 4.

The potential exposure value provided by the UK POEM model in the absence of personal protective equipment is 0.0240 mg/kg bw/day (> AOEL deltamethrin: 0.0075 mg/kg bw/day) which is not an acceptable level of risk. Wearing all protective equipment the exposure value is reduced by about 90% (Lloyd 1986; Methner and Fenske 1994; Soutar et al. 2000) and then equal to 0.0024 mg/kg bw/day (<AOEL), indicating the theoretical absence of risk when an operator is working in these conditions. Nevertheless, this model cannot be considered reliable enough to assess the potential exposure of the applicator to pesticide. This model may be more appropriate for Europe.

Table 4. Parameters used in the theoretical model UK POEM to estimate the potential exposure of operators (treated surface, working time and exposure reduction of 90% with PPE are default set parameters)

Application equipment	Backpack, hand-held sprayer
Formulation	EC (liquid, emulsifiable concentrate)
Concentration of active substance (deltamethrin)	25 g/l
Type and volume of packaging	Packaging(1 liter unspecified opening)
Dosage (l/ha)	1 liter, EC formulation
Applied volume (l/ha), rounded	260 (volume average: 20.7 l on 800 m²)
Treated surface (ha)	1 ha (default value)
Duration of work (mixture, loading, spraying, rinsing)	6 hours (default value)
Operator’s weight (kg)	60 kg (conventional WHO body weight)

DISCUSSION

The evaluation of the occupational exposure of farmers to pesticides is an integral part of the risk assessment for product safety and regulatory purposes. Several methods have been developed to assess exposure to pesticides and comprehensive reviews are available (Chester 1993; Davis 1980; Durham and Wolfe 1962; Van Hemmen and Brouwer 1995). In developing countries, sampling methods for assessment of exposure must be inexpensive and easy to use (Blanco et al. 2008). Qualitative and semi-quantitative methods such as Visual observations, Patch and Whole Body Methods are examples of such simple methods allowing an overall distribution on different body parts.

All of the distribution results obtained in these tests, whatever the method, are consistent with previous works and the results are roughly in agreement with those obtained by other authors using the same methods. Garrido Frenich et al. (2002) reported that the lower limbs were particularly exposed. Fenske (1990) showed that with a backpack sprayer, legs (right and left) were more contaminated with pesticides than other parts of the body. Syamimi et al. (2011) showed that during phytosanitary treatments in rice fields, the most exposed body areas are the lower parts of both legs. For Kim et al. (2013), the most contaminated body areas are the legs but also the chest when operators work in apple orchards (processing height).

The Visual Method using a dye or a ghost ink can provide a first rough indication but this sampling method tends to show contamination of body parts in reality poorly exposed. Results obtained were only qualitative and it was not possible to make a link between intensity of the coloration or spots and the quantity on the coverall (leading to overestimation of exposure). Observations of protective equipment (including under UV light) allowed an overall view of the distribution of the mixture on the operators' body. In the trials, visualization of deposits indicated that the hands have been heavily contaminated during the preparation and loading of the mixture until the rinsing of the sprayer. The legs, but also the back which supports the sprayer, appeared to be heavily contaminated compared to other parts. These observations are in accordance with those made by Ncamurwanko (2012), but this method should be limited to training demonstrations and cannot be considered as reliable to assess the distribution of pesticide on the body. The Visual Method should therefore be kept for educational demonstrations to risk-based awareness to operators. It can help them to understand that wearing safety equipment is crucial for their health.

Tests done with the Patch Method allowed quantitative observations of the distribution as tartrazine deposits were measured by colorimetry. This method appeared to be friendly and simple to use, inexpensive and had given very reliable measurements between repetitions (good reproducibility), despite extrapolations after deposits measurements. This method has been recommended by OECD (1997) to assess the distribution of pesticide on the body. However, it should be remembered that the Patch Method only estimates the amount of pesticide on the outer suit. This approach assumes uniform distribution of exposure over each body region in order to directly compare inner and outer patches. However, direct deposition through openings in the clothing will result in non-uniform exposure, as will splashes. An overestimation of the amount on the outer suit would lead to lower penetration factors and an underestimation would result in higher penetration factors (Soutar et al. 2000). The results of the trials have indicated a greater distribution of the mixture in the lower limbs (thighs and tibias) compared with other regions of the body. However, if the upper extremities (shoulder, arm and forearm) were far less contaminated than the legs, it appeared in the study that chest, neck and head could also be contaminated, even if they only received a small amount of the mixture. Contamination of various body parts, observable through the patch method, could be explained by the turbulence generated during application by the jet pressure and the forward movement of the operator in line. It was also observed that the legs are even more contaminated than the processing height is low (66.5% of deposits on the legs to 0.5 m against 41.4% at 1 m). Furthermore, the results show that the right leg is more contaminated than the left (the operators are right-handed). These results are in agreement with those obtained by Kadri et al. (2012). Moreover, when using a backpack device, the working height influences in part the general distribution of the mixture but also the level of contamination. These results corroborate and complement those obtained by previous authors (Hughes et al. 2006; Kadri et al. 2012; Kim et al. 2013; Ndao 2008).

In a study which compared the Patch Method with the Whole Body Method, Tannahill et al. (1996) concluded that the Patch Method was an acceptable method for estimating potential dermal exposure, but because the number of patches is rather limited and their spread cannot be able to represent the whole surface of the body, results were not reliable and not able to predict perfectly the distribution pattern of the pesticide during application. Therefore where a more accurate measurement is required, then a change of approach may be necessary. The Patch Method could be better used to compare various working situations (e.g. wind direction or speed, applied volume, height of plants, etc.) or the influence of the equipment used on contamination (sprayer or nozzle types).

Tests done with the Whole Body Method have produced a different pattern of pesticide distribution compared to the Patch Method. The thorax (chest and back) of the farmers' bodies appeared to be heavily contaminated, in accordance with Hughes et al. (2008) and Kim et al. (2013) findings, indicating that the pesticide could be dispersed directly on the entire body and not only on its bottom even if the legs were also heavily exposed during the operations. Therefore, although the Patch Method is simpler and less costly, the use of the Whole Body Method has been previously recommended (Machera et al. 1998). Results obtained from the Whole Body Method were more variable and influenced by the technique of each farmer, both to the observed contamination levels (from 368.37 to 2867 mg at the total/body) as well as on the distribution on the body (from 35% up to about 70% of the total amount on the thorax). Surprisingly, the arms and shoulders have received very little amount of the insecticide (about 1% of deposits). This observation is interesting because it demonstrates that it is not necessary to spend a lot of money - often limited - to equip operators with cartridges masks rather than to provide them with boots, coverall and waterproof pants. The thorax being very exposed (but without being able to distinguish the back or the torso), it is also necessary to cover it completely. Wearing waterproof apron in this case is a good solution because this equipment is less painful to bear than waterproof suits in hot climates (Nigg et al. 1992).

With quantitative data provided by the Whole Body Method, it has also been possible to understand the risk to an operator by comparing the observed deposits (total deposits on the body) to the value of the AOEL deltamethrin (0.0075 mg/kg bw/day). The average quantity on the body was determined equal to 1951.53 mg (n = 3). Considering an average body weight of 60 kg (WHO reference weight for an adult), the exposure value obtained (32.52 mg/kg bw/day) exceeds the AOEL. As it is admitted today (Fenske 1988; Nigg et al. 1992; Soutar et al. 2000) that wearing full protective equipment reduces exposure by 90%, the average exposure values for farmers wearing PPE is 3.25 mg/kg bw/day which still exceed the acceptable limit. It is interesting to note that the potential exposure value given by the theoretical model UK-POEM without body protection (0.024 mg/kg bw/day) is far away from the observed reality. The model predicts an absence of risk for the protected operators but it is clearly not true. The default parameters set in the

UK-POEM model prevent refining calculations: six consecutive hours are unrealistic, even if experimental results (Soutar 2000) showed that contamination occurs even after very short exposure, lasting as little as six minutes, suggesting that duration of spraying is not an important variable. Moreover, the pesticide distribution on the body included in the model is not consistent with the test results and the model, as well as the recommended patch sampling method, failed to predict the distribution of pesticide on the body: the model provides 25% of hands, 25% on the trunk and 50% on the legs, compared to 55% and 33% of average deposits on the thorax and on the legs respectively in the trial with the Whole Body Method.

The Whole Body dosimetry technique does not require any extrapolation and is far more realistic as mentioned by Soutar et al. (2000), but compared to the Patch Method, it seems more influenced by the way the operator worked. This can explain why the European legislation (Regulation (EC) 1107/2009) had recommended a minimum of 15 tests for GLP testing of operator exposure (Glass et al. 2002). Therefore a 'whole-body' sampling method should be recommended for the measurement of the real dermal exposure. In agreement with Chester (1993), for concurrent exposure and biological monitoring a refined Whole Body Method is recommended which involves the use of clothing representing that which workers normally wear under the prevailing conditions. Biological monitoring is recommended as the most precise means of estimating the absorbed dose of a pesticide, particularly if supported by human metabolism and pharmacokinetic data.

Finally, it should be noted that it is essential for the operator to be well trained to respect hygiene rules and Good Phytosanitary Practices because there are many factors that influence the exposure, such as the operator's skill (Hughes et al. 2008), the personal protective equipment (Ndao 2008), the type and crop height (Hughes 2008), the weather conditions (Hughes 2006; Kim et al. 2013), the type of device used and the orientation of the spray lance (Kadri 2012). This variability inherent in the technique and type of used device, where the human factor is much more decisive than for a large spray nozzles ramp, explains why the theoretical model was unable to predict reliably the level of exposure for a backpack sprayer. The model could be improved if these factors are introduced for a better predictive contamination level. But only practical testing conditions, based on prior observation of farmers' practices and tests performed with their help can give a realistic estimation of the potential exposure.

RESUME

Lawson A.J., Akohou H., Lorge S. et Schiffers B. 2017. Trois méthodes pour l'évaluation de l'exposition des agriculteurs aux pesticides dans des zones urbaines et péri-urbaines au Nord du Bénin. Tunisian Journal of Plant Protection 12: 91-108.

Les petits agriculteurs des zones urbaines et périurbaines du nord du Bénin utilisent des pesticides sans respecter les règles d'hygiène et sans équipement de protection individuelle (EPI). Sur la base de l'observation des pratiques locales à Djougou, Gogounou et Parakou, des essais sur le terrain ont été menés dans des conditions similaires pour évaluer la contamination et les niveaux d'exposition des agriculteurs, en utilisant trois méthodes d'échantillonnage habituelles (la Méthode Visuelle, la Méthode des Patchs et la Méthode du Corps Entier). Pour la Méthode Visuelle et la Méthode des Patchs, un colorant et de l'encre fantôme ont été utilisés comme traceurs. Dans les essais avec la Méthode du Corps Entier, la deltaméthrine (PLAN D 25 EC) a été utilisée comme traitement insecticide. Des dépôts ont été observés sur les équipements de protection et sur les collecteurs. La tartrazine a été mesurée par colorimétrie et la deltaméthrine par chromatographie en phase gazeuse avec un détecteur DCE (CG-DCE). L'examen des équipements de protection (Méthode Visuelle) a montré que l'ensemble du corps était potentiellement exposé aux pesticides. Les mains ont été contaminées pendant la préparation et le chargement du mélange jusqu'au rinçage du pulvérisateur. La Méthode des Patchs n'a pas été parfaitement capable de prédire la distribution de la contamination sur le corps des agriculteurs. Les résultats de la Méthode du Corps Entier sont apparus être plus variables et influencés par la compétence de chaque opérateur par rapport à la Méthode des Patchs. Les niveaux de contamination observés étaient en général supérieurs aux valeurs estimées avec un modèle théorique (avec un total de 368 à 2867 mg de deltaméthrine pour l'ensemble du corps). Avec le port d'EPI, l'exposition moyenne a atteint 3,25 mg/kg pc/jour. Sans EPI, l'exposition potentielle était égale à 32,52 mg/kg pc/jour. Ces deux valeurs dépassent très largement l'AOEL de la deltaméthrine (0,0075 mg/kg pc/jour) indiquant un niveau de risque élevé pour l'opérateur. Le modèle théorique utilisé (UK-POEM) n'a pas été capable de prédire les résultats d'exposition potentielle mesurés dans ces essais.

Mots clés: Evaluation de l'exposition, pesticides, petits producteurs, pulvérisateurs à dos

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ملخص

لاوسن، أرميل جويل وهرمين أكوجو وستيفاني لورج وبرونو تشيفارس. 2017. ثلاث طرق لتقييم تعرض المزارعين للمبيدات في المناطق العمرانية وشبه العمرانية في شمال البنين.

Tunisian Journal of Plant Protection 12: 91-108.

لحماية محاصيلهم من الآفات والأمراض، يستخدم المزارعون الصغار في المناطق العمرانية وشبه العمرانية في شمال البنين مواد كيميائية لوقاية النباتات. في غياب المعلومات والموارد الكافية، تتم المعاملات من دون التقيد بالحد الأدنى من قواعد السلامة وبدون معدات الحماية الشخصية. بناء على ملاحظات الممارسات المحلية في دجوغو وغغونو وباراكو، أجريت تجارب ميدانية في ظروف مشابهة لتقييم التلوث ومستويات تعرض المزارعين، وذلك باستخدام ثلاثة طرق لأخذ العينات (الطريقة البصرية، طريقة البقع، وطريقة الجسم الكامل) وبمقارنة النتائج التي تم الحصول عليها باستخدام كل من هذه الطرق. تستخدم الطريقة البصرية وطريقة البقع كعنصرين مقتفيين للأثر، الصبغة تارترازين أو الحبر الشبح. وفي اختبار طريقة الجسم الكامل، تستخدم الدلتاميثرين (PLAN D 25 EC). وقد لوحظت الرواسب على معدات الوقاية وعلى الجوامع. تم قيس رواسب التارترازين بواسطة قيس الألوان والدلتاميثرين بواسطة الكروماتوغرافيا الغازية (GC-ECD). وأظهرت ملاحظة معدات الحماية (بالطريقة البصرية) أن الجسم بأكمله يمكن أن يتعرض للمبيدات، ولكن بمستويات مختلفة. وقد تلوثت الأيدي منذ الإعداد وتحميل الخليط إلى الرش وأثناء التنظيف. لم تقدم طريقة البقع وطريقة الجسم الكامل نفس النتائج. فطريقة البقع لم تكن قادرة على التنبؤ بدقة، بتوزيع التلوث على أجسام المزارعين. أما في التجارب التي أجريت بطريقة الجسم الكامل، تبدو النتائج أكثر تغيرا وتأثرا بمهارة كل عامل مقارنة بطريقة البقع. ثبت أن صدر المزارع (البطن والظهر معا) ملوث بشدة بالدلتاميثرين، مع الإشارة إلى أن مبيدات الآفات قد تكون متناثرة على الجسم بأكمله وليس فقط على الجزء السفلي، حتى لو كانت الساقان معرضة خلال العمل. تظهر مستويات التلوث الملاحظة أعلى بكثير من القيمة المقدرة التي أصدرها النموذج النظري (مجموع 368 إلى 2867 مغ للجسم بأكمله) وبالنظر إلى متوسط وزن الجسم 60 كغ (الوزن المرجعي للبالغ الذي حددته منظمة الصحة العالمية)، بلغ متوسط قيمة التعرض 3.25 مغ/كغ من وزن الجسم/يوم (مع معدات الحماية الشخصية) أو 32.52 مغ/كغ من وزن الجسم/يوم (بدون معدات الحماية الشخصية)، الذي يتجاوز كل المستويات المحددة من طرف AOEL لدلتاميثرين (0.0075 ملغ/كغ من وزن الجسم/يوم) والنموذج النظري المستخدم من طرف UK-POEM غير قادر على التنبؤ بالنتائج المتحصل عليها في هذه التجارب الميدانية.

كلمات مفتاحية: آلة الرش الظهرية، تقييم التعرض، مبيدات ، مزارعون صغار

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