Is the World Health Organization Predicted Exposure Assessment Model for Space Spraying of Insecticides Applicable to Agricultural Farmers?

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Abstract

Agricultural farmers in developing countries are at high risk of pesticide exposure and adverse effects because of unsafe practices and inappropriate legislation. Biological monitoring is considered a useful tool for pesticide exposure assessment, however its use is limited in developing countries due to a lack of techniques and resources such as laboratory analysis, trained staff, and budgets. This study examines whether the *World Health Organization predicted exposure assessment model* (WHO-PEAM) is a suitable alternative tool for assessing insecticide exposure among agricultural farmers.

WHO-PEAM was used to predict daily doses (PDD) of chlorpyrifos for a group of Vietnamese rice farmers using a set of exposure parameters obtained from a questionnaire survey of participant farmers during a field study. These results were compared to absorbed daily doses (ADD) of chlorpyrifos for the farmers measured using a biological monitoring program, in which 24-hour urine samples were collected and analysed for the chlorpyrifos metabolite, 3,5,6-trichloro-2-pyridinol (TCP) using LC/MS. Validation of the model results was tested using the Wilcoxon Signed-Rank Test (WSR) and Two-way mixed-model Intraclass Correlation Coefficient (ICC).

The mean of total ADD was 20 $\mu\text{g/kg/d}$ while that of total PDD was 22 $\mu\text{g/kg/d}$. The WSR test revealed no statistically significant difference in the average values of ADD_T and PDD_T . ICC indicated substantial agreement for both single and average measures between ADD_T and PDD_T (ICC, 0.62 and 0.77 respectively). The results demonstrate that a refined WHO-PEAM model can be readily used as a field method, without biological monitoring, to evaluate chlorpyrifos exposure among agricultural farmers in Vietnam and similar developing countries.

Keywords: insecticide, exposure assessment, agricultural farmer, WHO-exposure model, biological monitoring

1.0 Introduction:

Small-scale farmers in developing countries are found at high risk of pesticide exposure when mixing, loading and spraying pesticides due to their unsafety practices, lack of personal protective equipment and appropriate legislation (Konradsen et al., 2003, Echobion, 2001). Like other developing countries, Vietnamese farmers, approximately 80% of the total labour force (Hung, 2003), are at high risk of pesticide exposure and adverse health effects due to use of back-pack sprayers for pesticide application, low safety knowledge, and insufficient use of personal protective equipment (Dung, 2006). Murphy et al (2002) indicated that 31% of surveyed farmers in northern Vietnam had at least one symptom of pesticide poisoning (Murphy et al., 2002), and Dasgupta et al (2007) found that 35% of farmers in southern Vietnam had blood cholinesterase levels indicative of acute pesticide poisoning and that 21% of the farmers had chronic signs of poisoning (Dasgupta et al., 2007).

Reduction of occupational health risk from pesticides among farmers requires a systematic risk assessment and management, in which evaluating or predicting the exposure level in various scenarios of application plays a crucial role in characterizing and reducing risk of pesticide adverse health effects (Maroni et al., 1999). Biological monitoring has been considered a useful tool for assessing occupational exposure to pesticides (Kappa-Skrzypczak et al., 2011), by which pesticide exposure can be evaluated by either measurement of pesticide, metabolites in the urine, blood and other specimens or measurement of a biological effect of pesticide such as inhibition of cholinesterase (He, 1993). However, this method requires time and is costly due to involvement of sophisticated sampling and analytical techniques. In addition, this approach is limited in the ability to quantify exposures for specific pathways since it measures the internal dose (Barr et al., 1999, He, 1993). Whereas, simple methods for surveillance of pesticide exposure and evaluating rapid local intervention have been frequently required in developing countries due to shortage of high

techniques and equipment and resources such as laboratory analysis, trained staff, and budgets (Wesseling et al., 1997).

The World Health Organization (WHO) developed the guideline “Generic Risk Assessment Model For Indoor and Outdoor Space Spraying of Insecticides” in 2010 and revised in 2011 (WHO, 2011), in which the insecticide exposures to applicators by different pathways including dermal, ingestion and inhalation are estimated by a series of predicted exposure assessment models (WHO-PEAM). The mixing, loading, and spraying scenarios used in WHO predicted exposure assessment models are similar to the pesticide practices applied by agricultural farmers in Vietnam and other developing countries. Nevertheless, no evaluation on applicability of the WHO-PEAM to the pesticide exposure assessment in agricultural farmers has been conducted.

The objective of this study is to examine whether the WHO-PEAM is applicable for measuring exposure levels of insecticide in farmers using the available results of a biological monitoring of chlorpyrifos exposure to rice farmers in Vietnam.

2.0 Methodology

2.1 Biological monitoring of chlorpyrifos exposure

The study participants comprised rice farmers (18) with an age ranged from 19 to 59 years in a typical agricultural commune in Northern Vietnam. The demographic information, lifestyle, health status, farm activities, insecticide application, personal protective equipment (PPE) were collected by structured questionnaire interviews and field observations.

The biological monitoring in this study was referred from several guidance documents such as US EPA Occupational and Residential Exposure Test Guidelines (US EPA, 1996), OECD Guidance Document on conducting studies of occupational exposure to pesticides

during agricultural application (OECD, 1997), and WHO Technical Monograph on field surveys of exposure to pesticides (World Health Organization, 1982). 24-hour urine samples (108) were collected from participant farmers for prior-, during-, and post-application of pesticides. Each farmer was required to collect a 24-hour urine sample for firstly one day within the week before the spraying application, secondly the spraying application day (all of 18 farmers just sprayed for one day only), and thirdly the 5 days following the application. For each 24-hour urine sample, on day 1 the farmers discarded the first void of urine when they arose, then they collected all urine in a given container for the next 24 hours. On day 2, the farmers urinated the first void into the given container as the last void for collection. The farmers were given the cooler box with dry ices in order to keep the samples during the sample collection. Then, all urine samples were stored at -20°C before analysis and then were analysed at Queensland Health Forensic and Scientific Service for 3,5,6-trichloro-2-pyridinol (TCP), the primary metabolite of chlorpyrifos, using pre-treated enzyme, and solvent extracted using methyl-ter-butyl-ether/hexane (30%), followed by concentration of extracts and analysis by liquid chromatography/mass spectrometry (LC/MS).

The total chlorpyrifos Absorbed Daily Dose (ADD_T), comprising baseline exposure level prior to the spraying event (ADD_B) and post-application (ADD_A) which were estimated using the approach described by elsewhere (Mage et al., 2004, Curwin et al., 2007). The ADD was calculated from a combination of individual urinary TCP and daily creatinine excretion rate taking into account of age, gender, height and body weight basis. The equation used to calculate ADD of chlorpyrifos is described below:

$$ADD = C.Cn.CF.R_{mw}/BW \quad \text{Equation 1}$$

where, ADD is Absorbed Daily Dose ($\mu\text{g/kg/d}$); C, concentration of TCP in urine per gram creatinine ($\mu\text{g/g creatinine}$); Cn, calculated mass of creatinine excreted per day (g/day); CF, correction factor of chlorpyrifos = 1.4 (approximately 70% is excreted as TCP in urine); R_{mw} , the ratio of parent pesticide and pesticide metabolite molecular weights; BW, body weight (kg).

The amount of urinary TCP collected in the post-application period was deducted by the amount of urinary TCP in prior-application before we calculated the ADD for post-application.

2.2 Estimation of chlorpyrifos predicted dose using the WHO model

The Predicted Daily Dose (PDD) of exposure to chlorpyrifos among participants farmers was estimated using Equations 2-5 described in the WHO Generic Risk Assessment Model for Indoor and Outdoor Space Spraying of Insecticides (WHO, 2011), in which the exposure levels were predicted for different pathways under the specific tasks of pesticide application, comprising: mixing and loading, and application of the insecticide product by spraying with manually carried equipment and washing and maintenance of the spray equipment.

For mixing and loading insecticide formulation, inhalation exposure is not considered significant, so the Dermal Predicted Daily Dose ($DPDD_{M/L}$) was calculated by following equation:

$$DPDD_{M/L}(\mu\text{g/kg/d}) = \frac{VF_{dermal} \cdot CF \cdot PPE \cdot AbsD \cdot EF}{BW \cdot AT} \quad \text{Equation 2}$$

where, VF_{dermal} is volume of formulation on hands using default values for potential hand contamination (ml/operation) during mixing and loading of a liquid pesticide formulation; CF, concentration of active ingredient in the formulation; PPE, protection provided by the gloves (0.1 for the guideline scenario, 1 for the lax standard scenario); EF, exposure frequency;

AbsD, dermal absorption of the non-diluted formulation; *BW*, body weight; *AT*, averaging time.

For application of insecticide formulation, washing and maintenance of the spray equipment, the Inhalation Predicted Daily Dose (IPDD_S) was quantified using Equation 3, and the Dermal Predicted Daily Dose (DPDD_S) was quantified using Equation 4.

$$IPDD_S(\mu g/kg/d) = \frac{CS.CA.RPE.BV.AbsP.EF}{BW.AT} \quad \text{Equation 3}$$

where, *CS* is concentration of the active ingredient in the spray in mg/ml, derived from the concentration of the active ingredient in the formulation, and its dilution for the spraying was calculated by multiplying concentration in the formulation and dilution for spraying; *CA*, concentration of the spray in the inhaled air; *RPE*, protection provided by the respiratory protective equipment (0.1 for the guideline scenario, 1 for the lax standard scenario); *BV*, breathing volume (total amount of air inhaled during the exposure): moderate activities, adults = 1.5 m³/h (US EPA, 1997); *AbsP*, Absorption from the respiratory tract (the default value is 100%); *EF*, exposure frequency; *BW*, body weight; *AT*, averaging time.

$$DPDD_S(\mu g/kg/d) = \frac{VS_{dermal}.CS.PPE.AbsD.EF}{BW.AT} \quad \text{Equation 4}$$

where, *VS_{dermal}* is volume of spray on hands; *CS*, concentration of the active ingredient in the spray in mg/ml, derived from the concentration of the active ingredient in the formulation and its dilution for spraying; *PPE*, protection provided by the gloves (0.1 for the guideline scenario, 1 for the lax standard scenario); *EF*, exposure frequency; *AbsD*, dermal absorption of the non-diluted formulation; *BW*, body weight; *AT*, averaging time.

The total Predicted Daily Dose (PDD_T) was quantified using Equation 5 as described below:

$$PDD_T(\mu g/kg/d) = DPDD_{M/L} + IPDD_S + DPDD_S \quad \text{Equation 5}$$

2.3 Statistical analysis

The descriptive statistics were used to describe the baseline characteristics of farmers (age, gender, weight, height), farming practices (amount of chlorpyrifos active ingredient used, exposure frequency, body coverage by PPE), and values of chlorpyrifos exposure doses (ADD_T and PDD_T). In order to validate the WHO-PEAM model, pair-samples T test or Wilcoxon Signed-Rank Test was used to compare the average level of observed exposure level (ADD_T) and (PDD_T) depending on normality distribution of these values, and Two-way mixed-model Intraclass Correlation Coefficient (ICC) was used to evaluate reliability in agreement of individual and average measures between ADD_T and (Predicted Daily Dose) PDD_T based on the analysis of variances. The IBM SPSS Statistic Version 20 was used to conduct data analysis (IBM Corp, 2011).

3.0 Results and Discussion

3.1 Baseline characteristics of participant farmers

The age of participant farmers ranged from 19 to 59 years (mean: 42.6 ± 2.7), comprising 13 males and 5 females. Their average weight and height were 53 ± 1.3 kg and 162 ± 1.7 cm, respectively (see Table 1). The health status of participant farmers was good based on general health examination carried by the district medical centre. The farmer's households had small-scale farms with an average area of 3100 m^2 .

The participant farmers in the research location used Lorsbane 30EC (Trade name) containing 300 g chlorpyrifos ethyl per litre packed into 20ml liquid concentrate containers (Cowles et al., 1998). To apply to the rice crop, the 20ml liquid concentrate of Lorsbane 30EC was mixed with 10 L of water in a backpack spray tank (10L). The average amount of chlorpyrifos active ingredient used was 104 g, and depending on the areas to be sprayed and personal ability, the number of application hours varied from 3 to 7.5 hours (mean: 5.2 ± 0.3). All farmers did not wear standard occupational protective equipment but used a normal hat

like cotton hat, mask or face-covers, long sleeve shirts and pants, and only half of them wore the boots. The percent of body surface areas of farmers covered by protective equipment ranged from about 65% to 85% (mean: $80 \pm 1.6\%$) which were calculated using the percentage values reported by a previous study (Graber et al., 1997).

3.2 Chlorpyrifos ADD estimated from biological urinary TCP

The results of biological monitoring and exposure assessment of chlorpyrifos with Vietnamese farmers were shown in Table 2 and reported by Phung et al, 2011(Phung et al., 2011b, Phung et al., 2011a). The baseline Absorbed Daily Dose (ADD_B) among participant farmers ranged from 0.03 to 1.98 $\mu\text{g/kg/d}$ with a mean of 0.24 $\mu\text{g/kg/d}$; whereas, the post-application Absorbed Daily Dose (ADD_A) ranged from 0.35 to 94 $\mu\text{g/kg/d}$ with a mean of 19.4 $\mu\text{g/kg/d}$, which is approximately 80 times higher than the mean value of ADD_B . For temporal changes in ADDs, the mean value of ADD_A increased to a peak in one day (24 hours) after the application day (4.8 $\mu\text{g/kg/d}$) from the baseline exposure level. This peak was 20 times of the baseline exposure level ($p < 0.01$). The chlorpyrifos ADD_A declined after 24-hour post application and fell to the baseline exposure level after approximately 120 hours. The total Absorbed Daily Dose (ADD_T) ranged from 0.4 to 94.2 $\mu\text{g/kg/d}$ with a mean of 20 $\mu\text{g/kg/d}$, which is slightly higher than the mean value of ADD_A but not statistically significant ($p, 0.9$). The results indicate that there is a subtle difference between ADD_T and ADD_A values (0.1 - 4.5%) due to the small contribution of baseline exposure levels. These results were also compared with findings from other populations worldwide in the published reports as mentioned above.

3.3 Chlorpyrifos PDD estimated using WHO-PEAM

3.3.1 Dermal Predicted Dose from mixing and loading activities

Farmers used 20 ml liquid packs of Lorsbane, containing 300 g/L of chlorpyrifos, to make up a 10 L spray mixture (0.6g/ml) in a back pack. The sealed package is cut and contents poured by hand through a wide mouthed inlet on the top of a back pack containing 5 L of water. Another 5L of water is added to the back pack to make up 10 L of spray mix. Residual liquid concentrate in the package is washed with water into the back pack. The back pack is then screw capped and mixed.

Direct contact with the concentrate (300 mg/ml) during cutting and pouring of the 20 ml package is considered to be a low probability event because of the ease of cutting and transfer through the wide mouth of the backpack inlet. It is assumed that for VF_{dermal} , 0.1 ml of diluted residual concentrate (1:10 ratio i.e. 30 mg/ml) was deposited on hands during transfer of residual washings each time into a container sized 10 L and diameter of 45 mm closure (PSD, 2007). Diluted concentration of active ingredient (CF) in washings from a concentrate package (20 ml) was 30 mg/ml. PPE , a factor of 1 was used because no hand protection is assumed. $AbsD$ was assumed to be 1% or 0.01(Nolan et al., 1984). EF was number of mixing and loading operations by individual farmers. BW was the measured weight of participant farmers. AT , average time for spraying is one day. The $DPDD_{M/L}$ calculated for individual farmers ranges from 5.4 to 15 $\mu\text{g/kg/d}$ with a mean of 10 $\mu\text{g/kg/d}$ (see Table 2).

3.3.2 Predicted Dose from application, washing and maintenance of the spray equipment

Inhalation Predicted Daily Dose (IPDD_s)

The Inhalation Predicted Daily Dose (IPDD_s) depends on the concentration in air, the rate and duration of inhalation and absorption via the lungs. For chlorpyrifos, the rate of absorption via the lungs is assumed to be 100%. The exposure parameters used to estimate IPDD_s include: CS , concentration of chlorpyrifos in the aerosol was 0.6mg/ml derived from 300g/L concentration in 20ml mixed with 10 L of water; CA , application concentration is

taken to be the quantity of spray mixture released into a volume of outside air. In this case, 20 L of spray mixture was applied per Vietnamese acre (360m^2). The airshed volume (V) for the farmer during spraying is assumed to be $360\text{m}^2 \times 2 \text{ m high} = 720\text{m}^3$. During spraying it is assumed 1% of the spray mist containing the chlorpyrifos remains in the air after a dilution ratio of 1:100. This ratio is assumed for outdoor residential fogging for insect control in a given volume of air. The value of CA given was 0.28 ml/m^3 ($20,000\text{ml}/720\text{m}^3$).

During the spraying, the farmers used different types of respiratory protection (see Table 1) resulting in different values of the RPE factors used in the Equation 3. For the farmers using a medical mask, a factor of 0.2 was applied, corresponding to the assumption of 20% chlorpyrifos absorption through the mask, whereas for farmers using a face-cover (cloth material) a factor of 0.8 was applied, corresponding to the assumption of 80% chlorpyrifos absorption through the cover. Farmers who did not use any respiratory protection, a factor of 1 was applied corresponding to the lax standard scenario (WHO, 2011). The breathing volume (V) for moderate activities during spraying ($BV=1.5 \text{ m}^3/\text{h}$) was applied (US EPA, 1997). The spraying hours (EF) and the body weight of participant farmer (BW) were individual values obtained from the survey (see Table 1). The IPDDs of individual farmers ranged from 2.3 to $32.5 \text{ }\mu\text{g/kg/d}$ with a mean of $11.3 \text{ }\mu\text{g/kg/d}$ (see Table 2).

Dermal Predicted Daily Dose (DPDDs)

The exposure parameters include: VS_{dermat} , the volume of spray on hands was 9.3 ml/hands per day (WHO, 2011); CS , concentration of the active ingredient in diluted concentration was 0.6/ml; the dermal absorption factor ($AbsD$) was assumed to be 1% (0.01) for exposed areas of skin (Nolan et al., 1984). The PPE factor of each individual farmer was corresponding to his body area covered by PPE (see Table 1), for instance, a factor of 0.8 was applied for Farmer 1 corresponding to about 80% of body area covered by PPE. Both EF ,

exposure frequency and AT , averaging time was 1 day; and BW , participant farmers' body weight was individual value (see Table 1). Using Equation 4, the values of $DPDD_s$ of individual farmers range from 0.65 to 1.05 $\mu\text{g/kg/d}$ with a mean of 0.84 $\mu\text{g/kg/d}$ (see Table 2).

Total Predicted Daily Dose (PDD_T)

The daily predicted dose of chlorpyrifos (PDD_T) was quantified by summing up dermal absorption and inhalation during mixing, loading, and spraying application using Equation 5. The values of PDD_T (see Table 2) ranged from 8.6 to 48.4 $\mu\text{g/kg/d}$ with a mean of 22 $\mu\text{g/kg/d}$. The inhalation predicted daily dose during spraying operation (mean percentage: 51%) made the biggest contribution in the total dose, and is followed by dermal predicted daily dose during mixing and loading (45%). The dermal predicted dose during spraying operation accounts for the smallest proportion in the total dose (4%).

3.4 Validation of the WHO-PEAM model

3.4.1 Comparison between ADD_T and PDD_T among Vietnamese farmers

The normality test, One-sample Kolmogorov-Smirnov statistic ($p < 0.05$) and the Normal Q-Q plot, indicated that the normality of ADD_T was violated, so the Wilcoxon Matched-Pair Signed-Rank test (WMS) was used to compare between the average ranks of ADD_T and PDD_T values. The total predicted daily dose, PDD_T (mean, 22 $\mu\text{g/kg/d}$) was slightly higher than the total absorbed daily dose, ADD_T (mean, 20 $\mu\text{g/kg/d}$), however the results of WMS test showed there was no statistically significant difference between PDD_T and ADD_T (p value, 0.18).

The correlation between predicted daily dose, PDD_T and absorbed daily dose, ADD_T was investigated using Spearman's rho test, and the results illustrated a strong, positive correlation between these two measurements ($r = 0.8$, $p\text{-value} < 0.05$) based on the

classification of Cohen (1988). The intra-class correlation coefficient (ICC) revealed substantial agreement for both single measures (ICC, 0.62; p-value < 0.01) and average measures (ICC, 0.77; p value < 0.01) between PDD_T and ADD_T. The PDD estimates yield a narrower range in exposure than the ADD. This data seems to suggest that low exposures are overestimated using the WHO-PEAM, while high exposures (of which there are very few) are underestimated. This could have very important implications for studies attempting to assess a dose-response relationship.

The cumulative frequency distributions (CFD) of ADD_T and PDD_T are presented in Figure 1. The regression lines were fitted for the values from 5 to 95% cumulative frequency ($r^2 = 0.94$ for ADD_T and 0.92 for PDD_T) with the regression equations shown below:

$$CF(\%) = 44.2 \times \log(ADD_T) + 7.3 \quad \text{Equation 6}$$

$$CF(\%) = 128.6 \times \log(PDD_T) - 116.5 \quad \text{Equation 7}$$

Figure 1 shows that the differences in the values of PDD_T compared to ADD_T were large at the low levels of exposure, and this difference decreased when the exposure levels were increased. The Relative Percentage Difference (RPD) between ADD_T and PDD_T was smallest at the 70th percentile of cumulative frequency (ADD_T, 26.3 µg/kg/d; PDD_T, 28.2 µg/kg/d; RPD, 7%), and the RPD ranges from zero to 53% corresponding to CFD from the 72th to the 95th percentile of cumulative frequency. The CFD also indicated that the cumulative frequency distribution of ADD_T (Std. deviation, 24.4) as more varied than that of PDD_T (Std. deviation, 11.8).

This is probably due to a wide variance within individual ADD values which were influenced by varied exposure parameters regarding pesticide safety practices such as exposure time continuity, personal protection, and safety behaviour during mixing, loading and spraying; whereas, for PDD_T values, some of the exposure parameters were assumed to be the same for every farmer when estimating the predicted dose. For instance, the farmers

used different personal protective equipment, resulting in the actual body coverage by PPE to vary from 63.5% to 84.8% among the Vietnamese farmers; whereas, there were only two scenarios (lax standard scenario, PPE equal 1; standard scenario, PPE equals 0.1) for predicted dermal exposures from mixing and loading. Another factor, which would vary between individuals, is the breathing rate that was assumed to be a constant value of 1.5 m³/h in the predictive model. Moreover, some other exposure factors were assumed constant such as the concentration of the airborne spray in the inhaled air, and dermal deposition of chlorpyrifos on the hands during mixing and loading. In practice, these factors are likely to vary between individuals depending upon working experience and safety knowledge.

3.4.2 Application of WHO-PEAM for agricultural farmers

The results of this case study indicate that the WHO-PEAM can be substantially applied for assessing insecticide exposure among agricultural farmers without the need for biological monitoring. However, the exposure parameters used in the model still need some modification to increase the precision of insecticide exposure assessment. First, the PPE factor used for estimation of dermal predicted dose has only two options: guideline scenario (PPE = 0.1) in which applicators are assumed to wear appropriate PPE according to the label instructions and the relevant WHO manual, and lax standard scenario (PPE = 1) in which applicators are assumed not to use PPE is used. Nevertheless, in fact neither guideline nor lax standard scenario is exactly right for agricultural farmers in developing countries, since they used various PPE for an insecticide application due to availability of the equipment and their safety behaviour. For instance, farmers in this case study were from none-users to almost guideline-PPE users. Therefore, exposure assessors need to improve the sensitivity of the PPE factors by collecting and using percentage of body area covered (% BAC) by equipment as an alternative PPE factor. How to estimate BAC was described by Graber et al (1997).

Likewise, the RPE factors (0 and 1) used in the inhalation exposure estimate needs to be estimated based on the assumed percentage of insecticides go through the own masks used by farmers. This might vary by different kinds of respirators.

Second, the concentration of the active ingredient in the spray (CA) used in inhalation predicted dose is applied for indoor house (volume of spray/m³ house). This is conservative and may not be appropriate for outdoor spraying mission. Alternatively, a box model approach, which is widely used for estimating inhalation exposure to gases and vapours in atmospheres, is described by Jayjock et al (2007). It can be used to determine the average concentration of a contaminant with a “box” of air. If the contaminant is entering the “box” or defined volume of air at a steady rate and leaving the outgoing air at the same rate then the average concentration in the box can be determined by the following equation:

$$C_{eq} = G/Q \quad \text{Equation 8}$$

Where, C_{eq} is the steady-state concentration (mg/m³), G is the rate going into the box (mg/h) and Q is the flow rate of air leaving the box (m³/h).

This study has several limitations which should be considered in evaluating the results.

Firstly, the sample size of farmers was relatively small (18 farmers) which may influence on the power of the statistical comparison and correlation. Second, the monitoring program was conducted once in a year. However, the season we selected for monitoring was the main and largest cultivating season of rice for the entire the year, so that this period would be relatively representative for the whole year. Finally, our study did not have data on the activities of other than applications that might result in additional exposures to the exposure media and environment. For example, dermal exposure from walking through plant material or water sprayed with pesticides. This might have resulted in under estimation of the total amount of exposures among applicators.

4.0 CONCLUSION

This is the first study to validate the WHO-PEAM model for dose estimation using the data obtained from a standard biological monitoring. This study showed that the WHO-PEAM model using field data can predict chlorpyrifos exposure doses in Vietnamese rice farmers that are comparable to doses derived from biological exposure assessment using advanced analytical techniques. The results revealed substantial agreement in chlorpyrifos exposure doses estimated using the WHO exposure model and biological monitoring exposure assessment with Vietnamese farmers. There was no significant difference between mean values of exposure doses estimated by the applied model and biological monitoring.

Overall, the methodology offers a practical screening tool for health risk management of farmers exposed to insecticides, especially during small-scale applications in developing countries. It demonstrates that the WHO-PEAM model developed for measuring insecticide exposure with indoor and outdoor space applicators can be readily used to estimate insecticide exposure with agricultural farmers in Vietnam, and other countries, where the farmers have the same pesticide application method. Parameters in the model may be usefully refined to reflect local application conditions. However, further external validation for individual reproducibility of the exposure doses estimated by these two methods should be conducted in various farmer populations.

Ethical clearance

The biological monitoring program was approved for ethical clearance by Griffith University Human Research Committee (HREC) and issued with authorization to be commenced from 14/04/2009 SU Protocol Number ENV/04/09/HERC)

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Figure 1. Cumulative plots of total exposure to chlorpyrifos (ADD_T and PDD_T) of Vietnamese farmers

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