

Pesticides Applicator Exposure Assessment: A Comparison between Modeling and Actual Measurement

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Abstract

The use of pesticides throughout the world over the years has attracted public attention and concerns regarding their impacts on human health and the environment. This has led to the institution of regulations in both industrialized and developing countries to manage their use and to reduce their negative impacts on the environment and human health. Usually risk assessments are conducted to identify the potential risks associated with any new a product for registration or an existing product for re-registration. Exposure assessment is a critical part of the risk assessment process, which is mostly done through laboratory based biological monitoring studies. These biological monitoring studies are expensive and time consuming, hence the need for computer based exposure assessment models which are perceived to be quick and less expensive and can be handily used by pesticides regulators throughout the world, especially in developing countries where there is low technology and weak financial muscle for those rigorous and highly sophisticated laboratory based biological monitoring studies. The purpose of the paper therefore, was to conduct exposure assessment using two recognized occupational exposure models (UK-POEM and the German Model) and to make a comparison between the results of the models and that of measured results from biological monitoring studies from open literature. The paper observed that these two exposure models under estimate exposure compared to the biological monitoring. It is therefore, recommended that for regulatory purposes these models could be used with caution, taking into account the conditions under which pesticides sprayings are done in a particular country for compliance with the conditions used as input for the development of these models.

Keywords: Pesticides, Applicators, Exposure Assessment, UK-POEM, German Model

1.0 Introduction

The use of pesticides in the world has led to concerns over the effects of pesticide exposures on humans and other non-target organisms. There is no doubt that such exposures can result in illness or death. The World Health Organization (WHO) estimated that approximately 500 000 human poisonings occur each year worldwide (WHO, 1981) and the number of fatalities has been estimated at greater than 10,000 per year (Loevinsohn, 1987). Although epidemiological data indicate that the primary hazards of exposures to pesticides are acute toxic reactions, these exposures have also been implicated as a possible risk factor for cancer in agricultural workers (American Medical Association, 1988).

Generally, there are three principal sources of human exposure to pesticides; occupational (including agricultural), non-occupational (for example non-commercial treatments of dwellings and workplaces, home gardening, etc.), and dietary, that is indirect exposure of the population through the use of pesticides on agricultural commodities (Saunders, 1988).

The major types of occupational exposures, in terms of the magnitude and frequency of exposure, are agricultural (mixers, loaders, applicators, and harvesters), professional pesticide applicators who treat dwellings and workplaces and workers in pesticide manufacturing plants. In general, these types of exposures are regulated by national agencies which set permissible limits on exposure and determine whether a particular use has an adequate margin of safety for the worker (Saunders, 1988).

The three principal approaches currently employed for evaluating occupational exposures to pesticides include; passive dosimetry, biological monitoring and physiological (Saunders, 1988). A fourth approach of exposure assessment being also applied especially by pesticides registration authorities and which is recommended especially for developing countries' pesticides registration authorities is modeling. Construction of models of exposure may provide a valuable tool for predicting and managing occupational (or other types) of exposure and alleviating the great expense of conducting studies for each chemical under each set of potential uses and exposure conditions. Research efforts in this area suggest that this approach holds promise (Chester and Hart, 1986; Nigg *et al.,* 1984), but more research is needed to develop models that may be applied under more than a single set of conditions.

1.1 Passive Dosimetry

The commonest type of passive method used to estimate occupational exposure is a combination of patches on the skin and clothing and hand washes to estimate dermal exposure and air sampling for the estimation of inhalation exposure (USEPA, 1987a; Reinert *et al.,* 1986; Durham and Wolfe, 1962). Usually, absorbent patches are placed on the skin in sufficient and strategic locations so as to estimate total dermal exposure. Patches are also placed on the outer garments to assess the effectiveness of protective clothing. After exposure to the pesticide under conditions of field use, the patches are removed and analyzed for pesticide content. Exposure to the hands can be estimated by swabbing, hand washes or absorbent gloves. Since the major portion of occupational pesticide exposure occurs to the hands, the method of assessment of this type of exposure is critical to the overall estimate of exposure. No single technique is fully satisfactory for determining exposures to the hands, as washing will not recover residues that are absorbed into skin (Wester and Maibach, 1985), and absorbent gloves may significantly overestimate exposure to the hands, because the gloves absorb or trap more pesticide than would be found in contact with bare skin (Reinert *et al.,* 1986; Davis *et al.,* 1983).

With regards to inhalation, a variety of techniques exist, ranging from modified respirators, which contain an absorbent material to powered air sampling devices placed near the breathing zone of the monitored individual (Lewis, 1976).

1.2 Biological Monitoring

This approach involves direct measurement of pesticides and their metabolites in blood, urine and occasionally tissues (Coye *et al.,* 1986a; Reinert *et al.,* 1986). Therefore, it is theoretically possible to estimate the actual absorbed dose, providing that sufficient information on the pharmacokinetics of the specific chemical is available.

Another common approach in this area is to monitor some physiological or biochemical parameters as an index of exposure, for example measurement of decreases in serum or erythrocyte acetyl-cholinesterase activity after exposure to organophosphate insecticides. Although frequently referred to as `biological monitoring', this approach might be more correctly categorized as `physiological monitoring' or `health surveillance', since a response rather than actual biological dose is measured. For example, measurement of serum (pseudo-) cholinesterase activity is a common method for estimating exposure to organophosphate insecticides. Even though one may infer exposure by this technique, it is difficult to estimate the dose that an individual has received and one could not identify the specific chemical involved by this technique alone. In addition, because of the wide variability in blood cholinesterase activity among humans, the utility of this technique depends on accurate pre-exposure baseline measurements in the monitored individual (Saunders, 1988).

1.3 Modeling

This approach involves the obtaining of pesticides use data from manufacturers, farmers and from others sources such as literature, which are fed into constructed computer models to generate exposure data which are in turn used to calculate potential risks to pesticides. This method is fast and less expensive compared to biological monitoring approach of exposure assessment. One disadvantage however, is its inability to estimate actual concentrations of the particular type of pesticides and the sources of exposure and their respective contributions to total exposure.

A wide variety of exposure models are currently employed for health risk assessments. Individual models have been developed to meet the chemical exposure assessment needs of Government, industry and academia. These existing exposure models can be broadly categorized according to the following types of exposure source: environmental, dietary, consumer product, occupational, aggregate and cumulative. Aggregate exposure models consider multiple exposure pathways, while cumulative models consider multiple chemicals (Michael *et al*, 2006).

The use of exposure models is currently fragmentary in nature. Specific organizations with exposure assessment responsibilities tend to use a limited range of models. The modeling techniques adopted in current exposure models have evolved along distinct lines for the various types of source. In fact, different organizations may be using different models for very similar exposure assessment situations. This lack of consistency between exposure modeling practices can make understanding the exposure assessment process more complex, can lead to inconsistency between organizations in how critical modeling issues are addressed (e.g. variability and uncertainty) and has the potential to communicate mixed messages to the general public.

An exposure model is ‘a logical or empirical construct which allows estimation of individual or population exposure parameters from available input data’ (WHO, 2000). Exposure models represent important tools for indirect exposure assessments. They are typically used where direct measurements of exposure or biological monitoring data are not available or where these techniques are not appropriate for the exposure assessment situation. Additionally, there are a number of benefits associated with the use of exposure models for quantifying human exposures:

- They can predict potential exposures for future or hypothetical releases or contact events.
- They allow the utility of existing data to be maximized by combining different types and sources into an analytical structure.
- The degree of complexity adopted by the model can be set according to the needs of the assessment.
- They consider exposures via multiple routes and pathways.
- They reduce the need for resource-intensive monitoring programmes.

Workers may become exposed to a variety of substances potentially hazardous to their health in the workplace. In order to assess the magnitude of such exposures, occupational exposure models have been in use since the early 1990s (Paustenbach, 2000). The Estimation and Assessment of Substance Exposure (EASE) model (HSE, 2000) and the Predictive Operator Exposure Model (POEM) (PSD, 1992) are two occupational exposure models used in the UK today (Michael, 2006) and GERMAN Model used in the Germany. POEM has a more limited scope, as it is designed to predict exposure levels experienced by operators preparing and applying pesticides in the UK under UK conditions. A European version of the POEM model (EUROPOEM) is currently in development (Anon, 1996; van Hemmen, 2001). Similarly the GERMAN Model is designed to predict exposure levels by operators preparing and applying pesticides in Germany and under German conditions.

1.3.1 UK-POEM (1990)

The UK-POEM data base as used in this study is a predictive tool used to estimate operator exposure to pesticides. In the application of the model, product details such as dose and spray volume, representative areas treated per day and methods of application are required. The model assesses exposure by differentiating two main activities; mixing/loading and application. In terms of personal protective equipment, the model assumes the use of gloves or none. Therefore in this study, exposure was assessed for both scenarios. The model assumes that the level of exposure depends largely on the container size. In this particular study the container size of 2l with any closures was used. The model caters for only formulations such as EC, SC, WP and WG. It does not contain data for the mixing of solid formulations. For this particular study, all the pesticides involved were the EC type hence there was no difficulty that could warrant extrapolations. With regards to method of application, the model makes a distinction between downward (low crop) and upward (high crop) spraying.

According EFSA report (EFSA, 2007) by Hamey P. *et al* of the pesticides safety directorate of the UK in collaboration with Steaurbaut W. *et al* of the Gent University, the UK-POEM is a straight forward and simple to use model. The model is based on studies carried out in part for the specific purpose of model development. However, not all the required information is publicly available.

1.3.1German Model (1992)

The German Model was another model applied in this study. Like the UK-POEM, the German model makes use of product details such as; formulation type, active ingredient concentration, dose and amount handled. It also looked at work rate and method of application. The model assesses exposure by differentiating two major activities just like the UK-POEM; mixing/loading and application. In terms of personal protective equipment, the model is more detailed than the UK-POEM. It assumes either no protection or protection with the use of half mask and gloves for the mixing/loading activity and either no protection or full protection with the use of half mask, hood + visor, gloves and coverall + boots for the application activity. Therefore, in this study, exposure was assessed for both scenarios.

The formulations included in the model include; liquids, powders and granules, hence the pesticides used in this study fitted well with the model since they were all the EC type insecticides. With regards to methods of application the models assumes downward and upward applications with tractor mounted and hand held equipment. Unlike the UK-POEM, the German model does not link level of exposure to container size and for that matter no mention was made of the type and size of container.

The model, according to EFSA report (EFSA, 2007) by Hamey P. *et al* of the pesticides safety directorate of the UK in collaboration with Steaurbaut W. *et al* of the Gent University has a straight forward structure and is simple to use. It however, has relatively small databases (mixing/loading) for two out of three formulations and for downward applications made with tractor-mounted equipment.

The purpose of this paper therefore, is to assess applicator exposure to pesticides under different scenarios by using the UK-POEM and the German Model and compare the results with measured exposures from biological monitoring studies obtained from open literature.

2.0 Objectives

The objectives of this paper include;

1. To search open literature on applicator exposure to pesticides under high crop and low crop application conditions
2. To extract exposure data from the open literature on high and low crop pesticides application scenarios
3. Extract pesticides application information from open literature sources to conduct applicator exposure assessment by modeling (UK-POEM & German Model)
4. To make a comparison between predicted exposure (modeling) and measured exposure (literature)
5. Make a comparison between two operator exposure assessment models (UK-POEM and German Model)

3.0 Methodology

The paper adopted an open literature search to identify references which reported measurement of exposure for operators. The exposure values reported in the literature, though varied considerably, were often in mg of exposure/person, mg/cm^2 of body surface or mg of exposure/kg active substance applied.

The data obtained from this open literature search were later on used in an exercise where the UK-POEM and German Model were applied and the predicted exposure values were compared with the measured exposure data from the various studies. In order for such comparisons to be made it was necessary to transform some of the exposure data reported in the open literature to allow exposure to be expressed in mg of exposure/person. However, for some of the studies it was not possible to do this transformation due to lack of details on the spray tasks. For such data, comparison cannot be made with exposure models.

The open literature search considered only two data sets; data from hand-held applications to high crops and data from hand-held applications to low crops.

3.1 High Crop Applications

For the open literature search on hand held applications to high crops, five studies were included in the data set. The five studies considered are:

3.1.1 Van der Jagt (2008): The effectiveness of PPE was assessed by monitoring the exposure of pest control operators applying chlorpyrifos. Hand-held spraying equipment used to treat walls, floors and other surfaces were involved. Two treatments were considered; first PPE of coverall, gloves and RPE were worn (baseline scenario). In the second treatment the same operators were then monitored using higher levels of PPE (RPE, longer gloves, coverall fitted with hood, chemical resistant boots). Mean values of potential dermal exposure (PDE), actual dermal exposure (ADE) and potential inhalation exposure (PIE) were given for the two treatments. Other than the mean time for the two treatments (41 minutes and 32 minutes) no information on the spray tasks is available (application rate, spray dilutions, total amount sprayed). A chlorpyrifos product label for a surface building treatment to control various pests and recommends a 0.5% spray solution. This value was used for the predicted exposures using POEM and the German model.

3.1.2 Edwards J. W. (2007): Exposure and risk of workers spraying fruit trees with Malathion and fenthion were assessed. The study was conducted in South Australia. Knapsack sprayers were used to apply Malathion while motorised hand-held spray equipment were used to apply fenthion. Dermal exposure monitoring of the whole body area was not undertaken. Dermal exposure is therefore, calculated from shoulder, forearm, head and glove measurements. Inhalation exposure data are only reported for fenthion applicators. There was lack of fenthion seen in hat sample and the study reports that the extraction procedure for the hat fenthion samples may not have been effective owing the absorbency of the hat material.

3.1.3 Baldi I. (2006): Pesticide contamination of workers in vine yards in France was assessed. The study reports on 4 spraying operations for workers spraying vines with mancozeb using backpack sprayers. Levels of actual dermal exposure for the body were monitored using patches attached directly onto the workers skin, *i.e.* underneath their clothing. Hand exposure was determined using a hand wash procedure. Measurements of inhalation exposure were also taken. For these spray tasks, a protective coverall and gloves were worn by three of the four applicators. The fourth applicator used no protective equipment and wore a tee-shirt and shorts

3.1.4 Choi H. (2006): Worker exposure to cypermethrin a synthetic pyrethroid during treatment of Mandarin fields was assessed. Four workers applied a 0.5 g/l cypermethrin spray solution to mandarin trees in Korea. Applicators applied approximately 300 litres of spray solution over 45 minutes using a hand lance connected to a power sprayer. The paper gives details of validation for method and field recovery. Dermal (PDE) and inhalation (PIE) exposure were monitored. The methodology for estimating whole body exposure from the patch sampling is not described. All measurements of PIE were below the limit of detection.

3.1.5 Machera K. (2001): Operator exposure following spray applications of the fungicide penconazole was determined. Applicators applying a penconazole spray solution to vines in Greece were monitored. Measurements of PDE and ADE were taken using the whole body dosimetry method. Hand exposure was measured using cotton sampling gloves worn over protective gloves, representing bare hands. Inhalation exposure was also monitored.

3.2 Low Crop Applications

Just as for the hand held applications to high crop, five studies were included in the data set for the open literature search for hand held applications to low crop. The studies involved are as follows:

3.2.1 Wan H. (1990): Applicator exposure to pesticides in tea plantations in China was assessed. Twelve applicators were involved in applying either cypermethrin or fenthion spray solutions to tea plantations. Applications were made using knapsack sprayers to treat crops either 0.6 m or 1.1 m high. Patch sampling was used to measure exposure to the body. Arm exposure was estimated from sampling of the chest and abdomen regions. Cotton sampling gloves were used to monitor hand exposure. The study only provides hand exposure data for three cypermethrin and three fenthion operators.

3.2.2 Machedo N. (1998): Operator exposure to pesticides (Paraquat) on Maize farms in Brazil was assessed. The study looked at the exposure from three different hand-held spray treatments, switching the nozzle position to the rear of the operator and lengthening the spray lance from 0.5m to 1.0m. Exposure was measured by the use of a copper tracer solution added to the paraquat spray mix. Dermal exposure for the workers body was monitored from patches positioned on external body parts including the face and feet. Hand exposure was estimated using cotton sampling gloves.

3.2.3 Asakawa F. et al (1996): The exposure of a single operator who treated cabbage crops in Japan with a permethrin spray solution was monitored. Applications were done using a hand-held (10 nozzle) spray lance connected to a stationary power driven sprayer. The applicator put on a pair of waterproof trousers during the spray task. Measurements of PDE were done using patch sampling. Some measurements were taken underneath the outer clothing (trunk, arms). Measurements for hand exposure were no taken. Actual dermal exposure values are not reported in the paper. Approximations have therefore been taken from a graphical representation of the results. The study also monitored inhalation exposures in the workers breathing zone.

3.2.4 Cowell et al (1991): Worker exposure to pesticides during mixing/loading and application was monitored. The study involved eighteen lawn care specialists who treated residential lawns using a spray gun connected via a hose (on a reel) to a spray tank located on a vehicle. Workers were monitored over a full working day. Mixing /loading and application tasks were monitored separately. Dermal exposure was monitored using patch sampling. Hand exposure was monitored using a hand wash procedure. Inhalation exposure was measured using air sampling in the workers breathing zone. Two of the workers wore protective gloves.

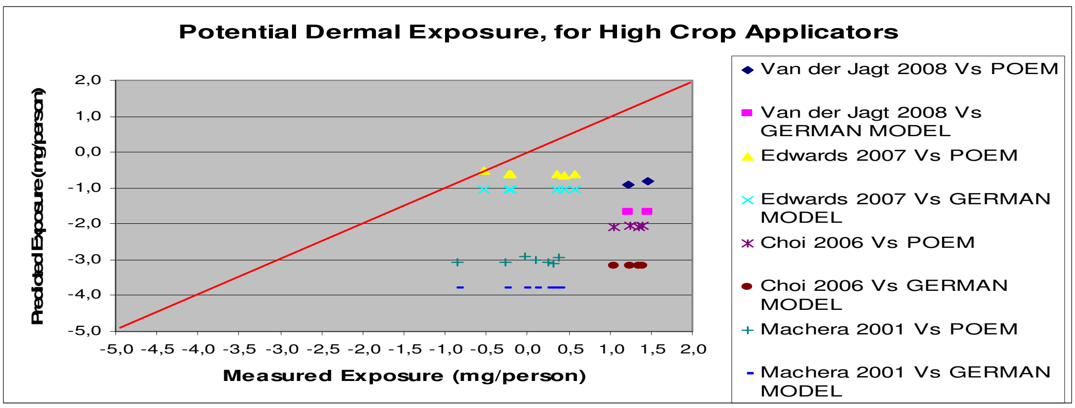
3.2.5 Slocum and Shern (1991): Exposure of experienced and novice applicators applying a stimulant pesticide (blue dye) to lawns was monitored. The blue dye was used as a surrogate for organophosphate lawn treatments. The study was designed primarily to investigate the effect of the level of experience of the applicator (experienced versus novice) and also spray volume per unit area (i.e. full rate and reduced rate). Potential dermal exposure (PDE) was monitored by means of whole body sampling of the coverall. Hand exposure was estimated using nylon sampling gloves. The study however, did not consider inhalation exposure. There were no significant differences between the different treatments.

4.0 Results and Discussion

As part of the production of the paper an open literature search was conducted for both high crop and low crop applications. This was to compare the measured exposure values in the respective studies with values obtained by the use of models (UK-POEM and German Models). The search took into account potential dermal exposure, potential inhalation exposure and actual dermal exposures for the various studies. The results of this open literature search are shown in the succeeding sections.

4.1 High Crop Applications

Five studies were obtained in the open literature search for high crop applications namely; Van der Jagt (2008), Edwards (2007), Choi H., (2006), Machera K., (2001) and Baldi I., (2006). The results for these studies, including the respective PDE, ADE, PIE and total exposure are shown in figure 1. The input data used for the calculation of the predicted exposure and the raw results obtained by both the UK-POEM and the German models can be found from Appendix A to L.



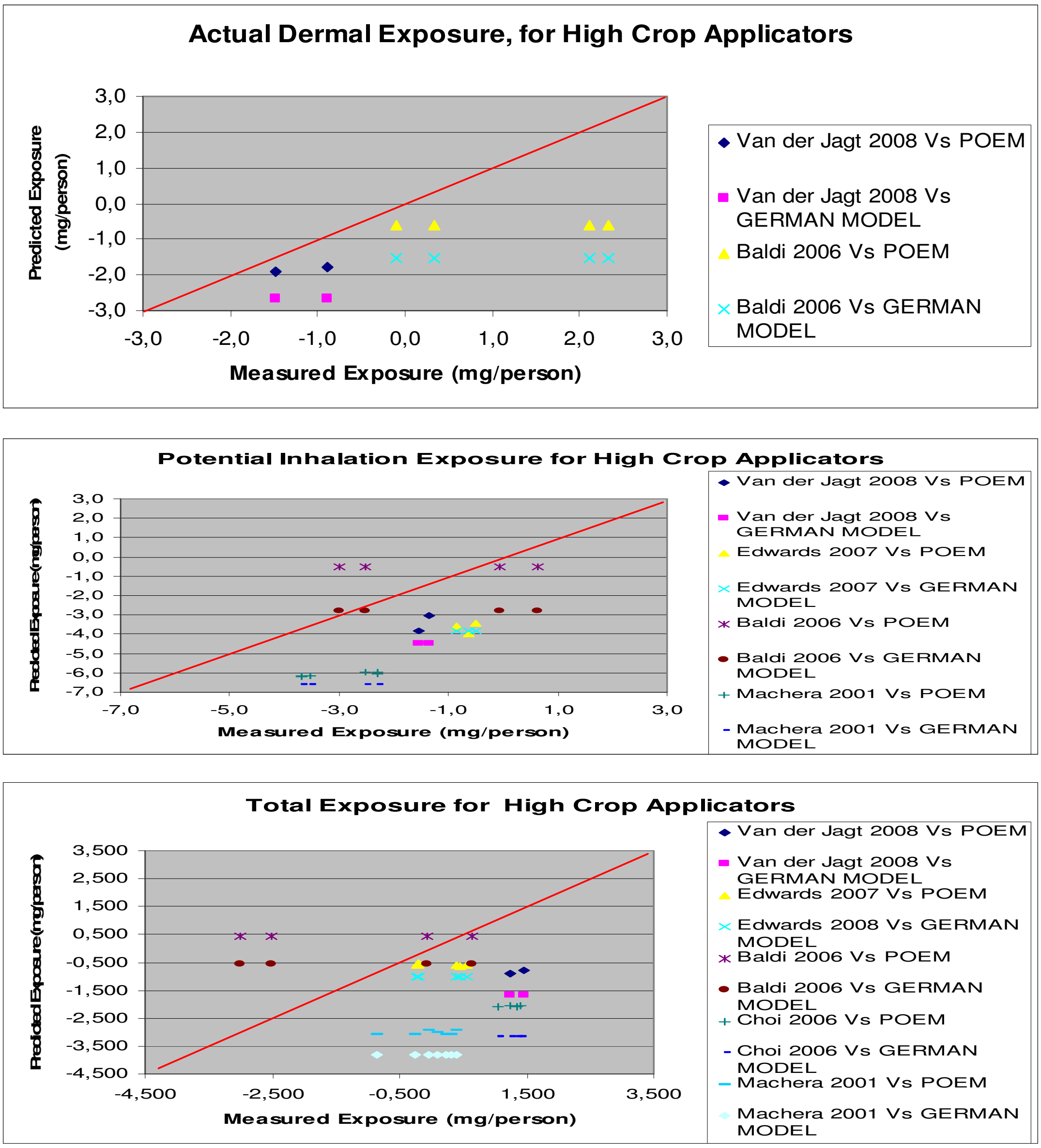


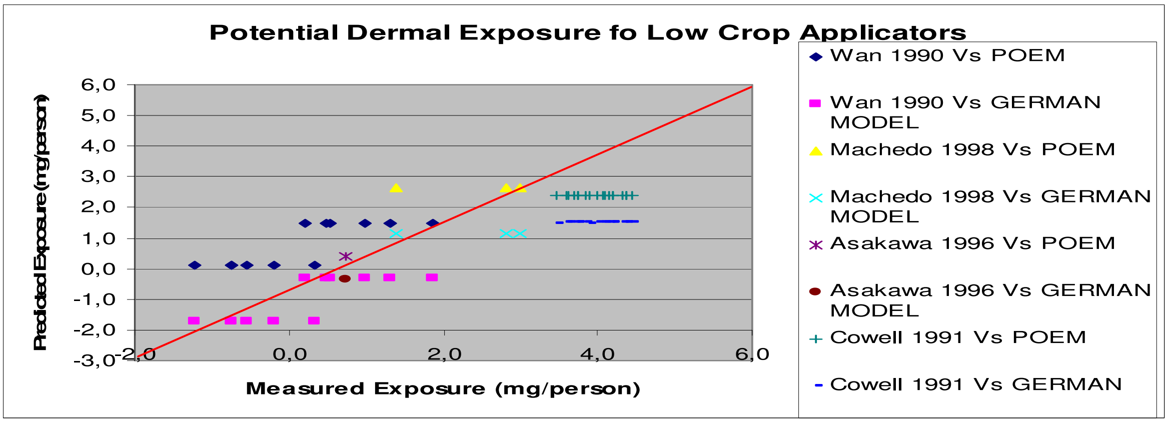
Figure 1: Comparison of predicted values of PDE, ADE, PIE and total exposure of high crop applications with those measured in literature studies.

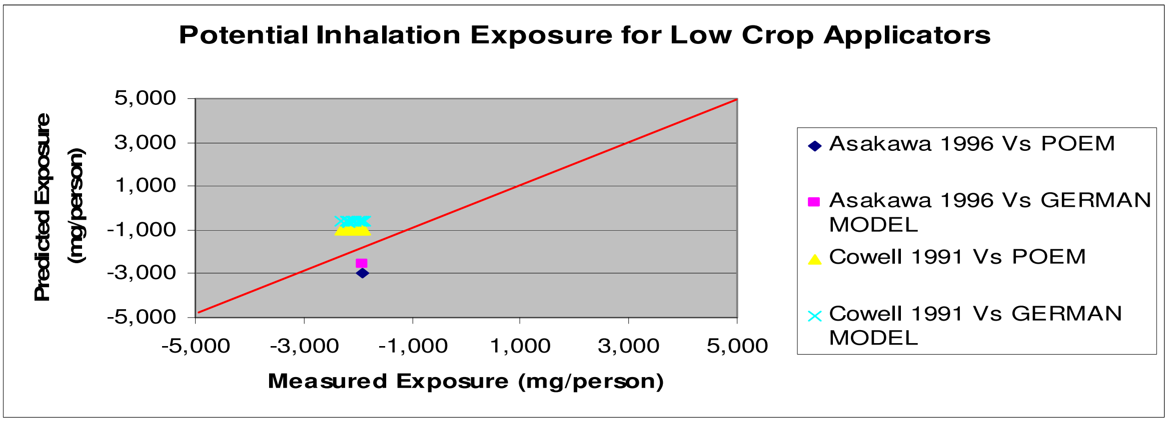
As can be seen from figure 1, five studies were obtained in the open literature data search for high crop applications. These studies provided measurements of potential dermal exposure (PDE), actual dermal exposure (ADE) and potential inhalation exposure (PIE). However, for the purpose of this study and to extend the data comparison further, the three exposure measurements as provided in the open literature studies were aggregated into total exposure. Out of the five studies considered, four studies measured dermal exposure by the use of patch sampling, while one study (Van der Jagt *et al*, 2008) used whole body dosimetry for PDE and patches for ADE.

From figure 1, it is observed that for PDE (mg/person) and ADE (mg/person) both the UK-POEM and the German model predicted exposure values are lower than the open literature measured exposures. For PIE (mg/person), both the UK-POEM and the German model predicted exposure values are closer to the measured exposure values in only one out of the five studies that is Baldi I. (2006). In the rest of the studies the predicted exposure values by the two models were lower than the measured values. For the total exposure, again it is observed that both the UK-POEM and the German model predicted exposure values are closer to the measured exposure in only the study of Baldi I. (2006). Hence with the high crop applications, it can be said that the models may be underestimating the exposures.

4.2 Low Crop Applications

The literature search for low crop applications obtained five studies, namely; Wan H. (1990), Machedo N. (1996), Asakawa F. (1996), Cowell (1991) and Slocum and Shern (1991). The results of the low crop open literature search with the respective PDE, PIE and total exposure are shown in figure 2. Due to lack of access to articles of the low crop application studies, the data for these results were adopted from a study conducted by Steaurbaut W. (unpublished).





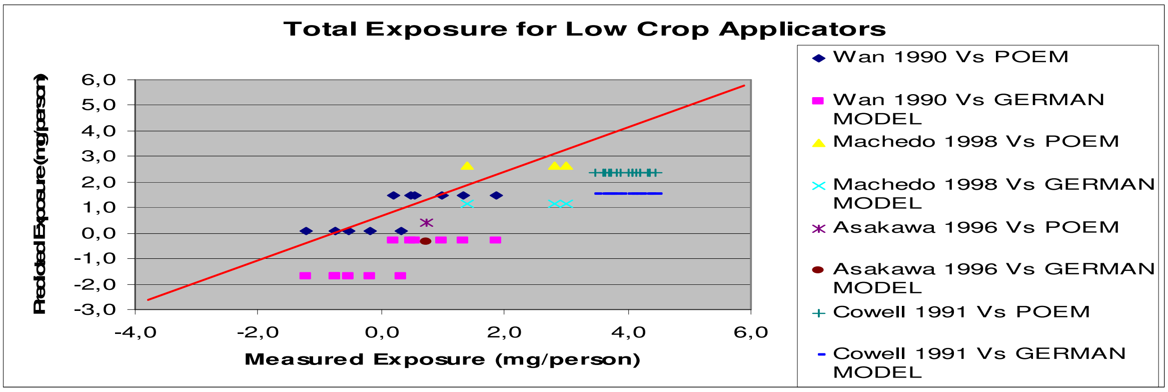


Figure 2: Comparison of predicted values of PDE, PIE and total exposure of low crop applications with that measured in literature studies.

As can be seen in the three graphs of figure 2, there are five studies in the open literature data search for low crop applications. However, due insufficient data of one of these studies to allow for exposure prediction using the UK-POEM and the German model, only four of the five studies are considered for exposure data comparison. The studies provide measurements of PDE and PIE, which for the purpose of this study are aggregated to generate total exposure values to extend the exposure data comparison. There were no data for actual dermal exposure. Patch sampling was used in these studies to measure dermal exposure of the body.

From figure 2, it is observed that for PDE, the UK-POEM predicted exposure values are a little higher than the measured values in the study of Wan H. (1990) while the German model predicted exposure values are a little lower than the measured values for the same study. The predicted exposure values for both the UK-POEM and the German model are closer to the predicted values in the study of Machedo N. (1998). However, the predicted exposure values for both models are lower than the measured values in the study of Cowell (1991). With regards to PIE only two studies provide data as can be seen in figure 2. For the PIE, both the UK-POEM and the German model predicted exposure values are higher than the measured values in the study of Asakawa (1998), but lower than the measured values in the study of Cowell (1991). For the total exposure, the UK-POEM and the German model predicted exposure values are more or less equal to the measured exposure values in the study of Wan H. (1990). In the rest of the studies, the predicted exposure values by the models are lower than the measured values. From these results, it can be said that the models are doing better in low crop application conditions than under higher crop application conditions.

4.3 High and Low Crop Applications Combined

As part of the open literature search the data for the low and high crop application were combined for a comparison to be made between the predicted exposure values and those measured in literature studies. The results of the combination including the respective PDE, PIE and total exposures are shown in figure 3 below.

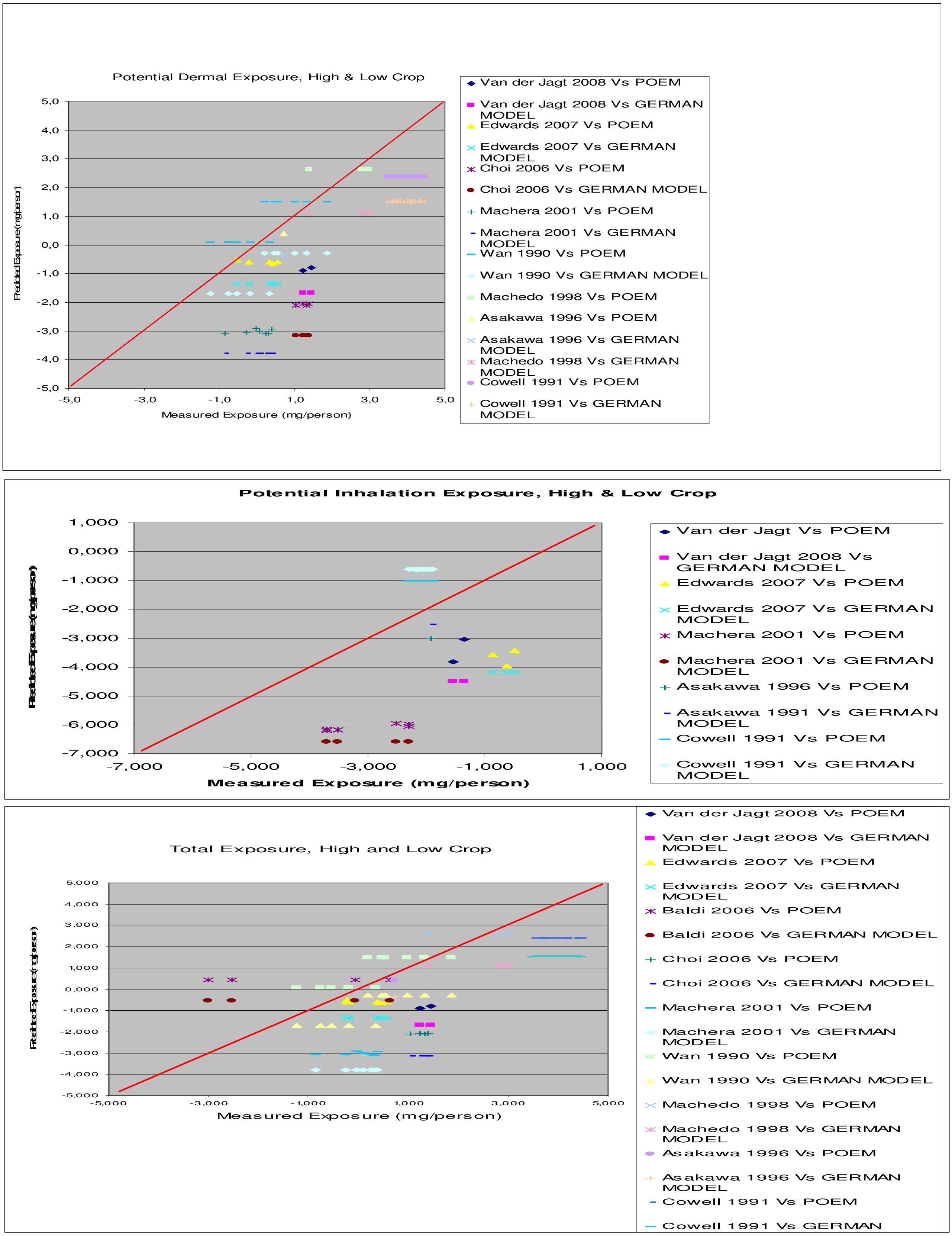


Figure 3: Comparison of predicted values of PDE, PIE and total exposures of a combination of low and high crop applications with those measured in literature studies.

From figure 3 where the open literature data for the high and low crop applications are combined, it is observed that predicted exposure values for the UK-POEM are closer to the measured values in the study of Wan H. (1990) while for the same study the predicted exposure values for the German model are lower than the measured exposure values. Also, in the study of Machedo N. (1998) the UK-POEM predicted exposure values are closer to the measured values. However, in the rest of the studies, the predicted exposure values for both models are lower than the measured exposure values. For the PIE, it is observed that, apart from the study of Cowell (1991) in which the UK-POEM and the German model predicted exposure values are higher than the measured exposure values, the rest of the studies have the model predicted exposure values lower than the measured values. For the total exposures, it is observed that the predicted exposure values for both the UK-POEM and the German model are closer to the measured values in the study of Baldi I. (2006). However, in the studies of Wan H. (1990) and Machedo N. (1998), while the UK-POEM predicted exposure values are still closer to the measured exposure values, the predicted exposure values for the German model are lower than the measured values. Still, from figure 3, it is noticed that in the rest of the studies, the predicted exposure values for both models are lower than the measured values.

From the open literature data set as can be seen in the above results, it can be deduced that though it is quick and easy to get operator exposure information from exposure models, such models are sometimes flawed by underestimating exposures. Also, it can be observed that the German model is characterized by more exposure underestimation than the UK-POEM.

5.0 Conclusion

Pesticides exposure models in general, have in some cases the tendency to underestimate exposure. However, among the models some are more accurate in estimating exposure than others. In this study, the UK-POEM was better in accurate exposure estimation than the German model. Both models appear to perform better under low crop application conditions than under high crop application conditions.

Exposure modeling as observed in this study and through other literature, holds the key to the future of pesticides management and control decisions especially for pesticides regulators in developing countries as these models are very fast in predicting exposures and less expensive compared to laboratory based pesticides exposure and risk assessment. However, the conditions under which pesticides sprayings are done in a particular country have to be checked for compliance with the conditions used as input for the development of these models.

Indeed, each approach has significant strengths and weaknesses, and no single approach will provide a complete estimate of exposure.

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