ASSESSMENT OF ENVIRONMENTAL PESTICIDE EXPOSURE OF FARMERS LIVING NEARBY THE PADDY FIELDS USING MATHEMATICAL MODELLING

by

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DECLARATION

I declare that this thesis entitled "Assessment of Environmental Pesticides Exposure of Farmers Living Nearby the Paddy Fields using Mathematical Modelling" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : ________________________________

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Date : 16th JANUARY 2020

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Assessment of Environmental Pesticides Exposure of Farmers Living Nearby the Paddy Fields using Mathematical Modelling

ABSTRACT

Paddy farmers can be exposed to pesticides while handling pesticides, but they may also be indirectly exposed to applied pesticides in the fields, by living nearby the agricultural fields. This study investigates how pesticide usage of the farmers in the paddy field may affect pesticide exposure and associated risk for paddy farmers living 100 m downwind from the treated area. A mathematical model developed by Wong et al (2017) was used to estimate the aggregated daily exposure to pesticide via inhaled vapour and indirect dermal exposure with contaminated ground. Risk was expressed as a hazard quotient (HQ) based on the total estimated exposure from the model and the no observed (adverse) effect level (NO(A)EL) for reproductive/developmental effects for the respective active substances. Results show that the aggregated HQs at 100 m proximity from paddy fields were <1, indicating relatively low risk of adverse development/reproductive effects among the selected paddy farmers.

Penilaian Pendedahan Persekitaran oleh Racun Perosak terhadap Pesawah Padi yang Tinggal Berdekatan Sawah Padi Menggunakan Pemodelan Matematik

ABSTRAK

Pesawah padi boleh terdedah dengan racun perosak sewaktu penyediaan racun, tetapi juga berpotensi terdedah kepada racun perosak sewaktu penggunaannya di sawah padi. Kajian ini bertujuan menyiasat pengunaan racun oleh pesawah sewaktu di sawah padi dan perubahan yang berkaitan kepada pendedahan dan risiko bagi pesawah yang tinggal 100-meter diparas tiupan angin daripada kawasan yang dirawat. Model matematik yang dihasilkan oleh Wong et al. (2017) telah digunakan bagi menganggar pendedahan harian agregat terhadap racun perosak melalui pendedahan wap dan pendedahan secara tidak langsung. Risiko dinyatakan dalam 'hazard quotient' (HQ) berdasarkan pendedahan keseluruhan daripada model dan 'no observed (adverse) health effect' (NO(A)EL) bagi menilai kesan terhadap pembiakan dan perkembangan daripada bahan aktif tertentu. Hasil menunjukkan bahawa agregat HQs pada jarak 100-meter daripada sawah padi adalah kurang daripada 1, menunujukkan risiko yang agak rendah terhadap risiko pembiakan dan perkembangan antara pesawah padi.

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LIST OF ABBREVIATION

AI	Active Ingredient
DARs	Draft Assessment Report
HSDB	Hazardous Substances Data Bank
HQ	Hazard Quotient
IPCS INCHEM	International Programme on Chemical Safety
IRIS	Integrated Risk Information System
JMPR	Joint Meeting on Pesticide Residues
KADA	Kemubu Agriculture Development Authorities
NO(A)EL	No Observed (Adverse) Effect Levels
RARs	Renewal Assessment Reports
TOXNET	Toxicology Data Network

LIST OF SYMBOLS

%	Percentage
˚C	Temperature (degree Celcius)
≤	Less than or Equal to

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Usage of pesticides is a prevalent strategy in controlling agricultural pests and diseases in order to minimise the crop loss and to maintain the crop productivity. A pesticide product comprises of single active substance or mixtures of active substances purposely designed for destroying, avoiding, repelling or mitigating the target pests and crop diseases, including that for plant regulator, defoliant and desiccant (EPA, 2018). Paddy rice is the second most essential crop after wheat in the world, with Asia is the largest producer with about 94% of the total world production. More than half of the world's population are depending on rice as the staple food (IRRI, 2006). Pesticide application is a seasonal and an occasional task as one of major tasks inaugurated by farmers (Damalas & Eleftherohorinos, 2011). In rice paddies, the use of pesticides is extensive due to the issues of insect pests and crop diseases as the major factors contributing to decreases in rice production (Fahad et al., 2015).

There are a range of pesticide types but the usage of insecticide, herbicide and fungicide are typically extensive. The role of each pesticide type is differed in which, insecticides used to control insects, herbicides used to control weeds and any undesirable plants, fungicides used to control fungi including molds, rusts and blight and nematicides used to kill parasites of plant (Yadav et al., 2017). The World Health Organization (WHO) has classified pesticide products into four major categories according their toxicities, comprising Class I for extremely hazardous to highly hazardous pesticides, Class II for very hazardous pesticides, Class III for moderately hazardous pesticides and Class U for those unlikely to present acute hazard (Ali et al., 2018). Because of the intrinsic toxicity of pesticides, extensive use of this class of chemicals may cause a range of health effects in exposed human, particularly farmers who often handle large amounts of pesticides.

Paddy farmers can be exposed to pesticides through both occupational and environmental exposure. Occupational exposure to pesticides usually occurs throughout the processes of mixing or loading, applying pesticide solutions and cleaning the equipment as the major routes of pesticide exposure (Gangemi, et al., 2016). Nevertheless, farmers living nearby agricultural fields can also be exposed to pesticide vapour drifts that may further increase their pesticide exposure. Pesticide drift during the application whereas pesticides volatilisation happens shortly after application and can last up to a few weeks. Vapour drift mainly occur when active substance volatizes during application or several hours afterward. The volatility depends on the chemical's vapour pressure and higher temperature will increase the vapour drift

Generally, exposure to pesticides can cause a range of health effects ranging from acute to chronic effects, including respiratory tract irritation, allergic sensitisation, eye and skin irritation, nausea, vomiting and diarrhoea, Parkinson's disease, asthma, neurological deficits, respiratory diseases and cancers (Sanhok et al. 2017; Kim et al. 2017). Studies have associated the duration of farmers' residency and household proximity to agricultural area with DNA damage and the detection of pesticides in the urine among the farmers and their children (Rodriguez et al. 2013;

How et al. 2015) in a study conducted by Tuc et al. (2007), the household distance less than 300 m from the rice fields and those with farming experience over 10 years had been associated with abnormal semen characteristics in rice farmers.

1.2 Problem Statement

Farmers who live adjacent to rice paddies, normally take no action to avoid or control exposure and thus can be exposed to pesticides over longer period via environmental exposure (24 hours exposure per day). This is because residential factor is a less commonly adjusted risk factor (How et al. 2015). Typically, the household proximity to the agricultural field and duration of residency are indicator factors for farmers exposure to vapour drifts of pesticides. Much studies have been conducted for reproductive/developmental effects of pesticides on farmers, however, adverse health effects of farmers exposed to pesticide drifts may vary depend on the amount of pesticide applied, the toxicity of pesticide, the prevailing weather conditions and the period of pesticide remains in the environment compartments after application (Damalas et al., 2011). Therefore, this study investigates how pesticide usage may influence the exposure and associated risk in space and time among farmers living nearby the paddy fields.

1.3 Objectives

The objectives of this study are:

i. To identify the level of environmental pesticides exposure of paddy farmers at 100 m distance downwind from the edge of paddy fields.

ii. To investigate how pesticide usage and associated exposure may vary across a cropping session.

1.4 Scope of Study

Study was conducted among paddy farmers from both Pasir Puteh and Tanah Merah, Kelantan via face-to-face interview and the distribution of questionnaire forms. Mathematical exposure model developed by Wong et al. (2017) was used in this study, using the total amount of pesticide active substances applied on a single spraying day as the key input parameter in the exposure estimation for the selected distance at 100 m downwind from the edge of the fields. The NO(A)EL values for reproductive/development effects were used as the referenced points for health issues. NO(A)EL is the highest dose or the exposure level of a substance that produces no noticeable (observable) toxic effect.

1.5 Significant of Study

Substantial number of studies have been conducted to assess the farmers' exposure to pesticide under a range of working scenarios, with limited data available for their environmental exposure to pesticides by living nearby agricultural fields. Study findings can be used to identify the potential of environmental exposure as an additional source of paddy farmers' exposure to pesticides by living nearby treated fields and associated health risk.

CHAPTER 2

LITERATURE REVIEW

2.1 Rice Cultivation

Rice is a staple food for about two billion people in Asia and hundreds of million people in the Africa and Latin America (Lincoln, 2018). In 2017, more than 80% of the world's rice were consumed by countries in Asia with increasing demand can be expected (Omar et al., 2019). Cultivation of rice can be influenced by the climatic and soil conditions, but typically requires high temperatures between 20˚C and 40˚C as a tropical and sub-tropical plant (Ane et al., 2016). An entire rice cropping season takes between three to six months to grow from seeds to their mature grain, comprising of ten crop stages in a growth cycle as shown in Table 2.1.

Table 2.1: Crop stages of a complete growth cycle for the paddy plant

Stages	Crop stage
I	Germination and emergence
II	Seedling
III	Tillering
IV	Stem elongation
V	Panicle initiation
VI	Panicle development
VII	Flowering
VIII	Milk grain
IX	Drough grain
X	Mature grain

(Source: Heinrichs, 2018)

2.2 Pesticide Use in Paddy Field

In rice paddies, almost one third of paddy production are generated by using pesticides to ensure the reliability of paddy growth. Studies indicated the most abundantly applied pesticides in rice paddies are insecticides, followed by fungicides, and herbicides (Sapbamrer and Nata 2014; Scattler et al. 2018). These three pesticide types are the most commontly used in paddy plantation. According to How et al. (1980), there were around 187 species of insects attacked the rice production. There were about 800 insect pest species investigated to attack the rice crop that required mixtures of insecticides to combat the insect growth (How et al. 2015). Typically, amount and type of pesticides used in paddy crop are dependent on the type of pests and their potential damages to the crop.

Rice pests have the potential to transmit various diseases and cause direct damages to rice plants. For example, rice plants can be attacked by the pests when the insects chewing the plant tissues, borer the paddy stem or sucking the fluid saps from the stem and grains which resulting in low crop yields (Ane et al., 2016). Table 2.2 shows some major insect pests of rice in Malaysia.

Table 2.2: Major insect pest of rice in Malaysian paddy fields

Common Name	Scientific Name
Rice stem borer	*Chilo polychrysus*
Rice armyworm	*Spodoptera mauritia*
Malayan black bug	*Scotinophora coarctata*
Caseworm	*Nymphula depunctalis*
Rice leaf folder	*Cnapalocrocis medinalis*
Green leafhopper	*Nephotettix virescens*
Rice ear bug	*Leptocorisa oratorius*
Rice brown planthopper	*Nilaparvata lugens*
White-backed planthopper	*Sogatella furcifera*

(Source: Ahmed et al., 2012)

2.2.1 Active Substance in Pesticide Product

Pesticide products consist of two main types of ingredients, namely active ingredient and inert ingredient. Active ingredients are the chemicals in the pesticide products that act to control the pests whereas inert ingredients play important roles to improve the effectiveness and performance of pesticide products. Each pesticide product usually consists of at least one active ingredient. Generally, active ingredient is not applied in their pure form but with the addition of inert ingredient that help in improving their storage, application, effectiveness or safety.

Typically, each pesticide product is labelled with the name of single active ingredients and their respective concentrations in the formulations. Different product brands may have the same active ingredients and concentrations. Pesticide products with low toxicity are often labelled with “CAUTION” instead of “WARNING” or “DANGER” (NPIC , 2019).

Table 2.3: Definitions for different types of pesticide and the respective active ingredients

Type of Pesticide	Description	Active ingredient
Herbicides	Design to kill plants and controlling weeds	chlorophenoxy glyphosate paraquat/diquat
Insecticides	Control insects	boric acid carbamates/organophosphates organochlorine pyrethoids
Fungicides	Kill or slow the growth of fungi and their spores	tricyclazole difenoconazole

(Centers for Disease Control and Prevention, 2017)

2.3 Environmental Pesticide Exposure

Farmers are still exposed to pesticides although they are not performing any pesticide activities due to the vapour drift from nearby treated field or through indirect dermal contact with pesticide deposits on the contaminated ground. Environmental exposure can come in contact with farmers through the environment (indoor and outdoor air) exposure or can occur via airborne emissions. Environmental exposure to pesticides can be influenced by the proximity of the residency area from the area treated by pesticides (Mamane et al., 2014). Other influencing factors include the type of formulation used, physico-chemical properties of pesticides and weather conditions. Each pesticide has different vapour pressure and have different in toxicity (Hamsan et al., 2018).

2.4 Pesticide Toxicity

Risk are dependent on the toxicity of a chemical and the probability of exposure to the chemical (Fig. 2.1). Basically, toxicity is the capacity of substance to cause illness or death while risk is the combination of both toxicity and exposure. Pesticide toxicity in exposed humans is dependent on the duration of exposure and how fast the toxic symptom develops (Abdullah et al., 1997).

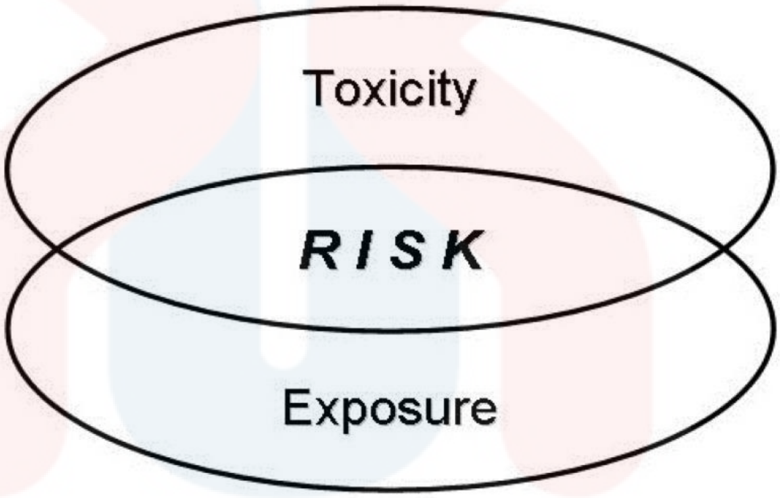

Figure 2.1: Toxicity and exposure are the major factors of risk. (Source: Damalas et al., 2015)

Generally, pesticide toxicity can be divided into three types and that might be affected by the number of exposures to a poison and time it takes for toxic symptom to develop (Eldridge, 2008; Table 2.4). Acute toxicity refers to a pesticide poisonous to an organism after a single short-term exposure that the effect might appear immediately (within 24 hours) of exposure. In contrast, chronic toxicity refers to poisonous of pesticide due to frequent incidents of exposure up to a few months or years (long-term exposure). Chronic toxicity is able to cause adverse health effects for extended period of time. Highly toxic pesticides have higher potential to cause human health effects compared to pesticides that are less toxic. The potential of poisoning is influenced by the concentration of pesticide in a formulation, the length of human exposure to a pesticide and the route of entry into the human body (Eldridge, 2008).

Table 2.4: Types of pesticide exposure and their definition

Types of Exposure	**Definition**
Acute exposure	Ability of chemical to cause injury from a single exposure in a short duration.
Chronic Exposure	Repeated or continuous exposure of pesticide to a person.
Sub-chronic Exposure	Repeated and continuous exposure of pesticide, but show no quantifiable result on toxic effects.

(Source: Eldridge, 2008)

2.5 Health Risk from Pesticide Exposure

There has been arising health issues due to the intrinsic toxicity of pesticides and their uses on the farm workers (Sapbamrer et al., 2014). Health risk of pesticide exposure depends on pesticide chemical groups and toxic properties, for instance, organophosphates exposure can lead to the inhibition of the enzyme cholinesterase and result in nervous disorders (PSEP, 2015).The danger of pesticide exposure usually increases along with the exposure concentration and uptake dosage, frequency of exposure and the respective chemical toxicity (Kim et al., 2016).

Pesticides can cause a variety of health risk ranging from acute to chronic effects. Every year, there are about three million cases reported due to acute pesticide poisonings (Dahab et al., 2017). Health symptoms due to acute toxicity can occur within 24 hours from the exposure, including respiratory tract irritation, allergic sensation, eye and skin irritation, nausea, headache and extreme weakness (Pinggali, 2012; Sankoh, 2016). For instance, acute effects of organophosphate poisonings can cause cholinergic dysfunction, muscle weakness, coma and respiratory failure (Hung et al., 2015). The Disease Control Department in Thailand reported that 13.54% from 100,000 people had been hospitalised in 2009 mainly due to the use of organophosphates, herbicides and carbamates in farming activities (Sapbamrer et al., 2014).

Meanwhile, chronic or long-term toxicity occurs at low level of exposure over prolonged period and do not show immediate effects, including Parkinson's diseases, asthma, neurological deficit, respiratory diseases, cancer such as leukaemia and non-Hodgkin lymphoma (Kim et al., 2017). According to Kaplan (2001), long-term pesticide exposure can cause chronic health problems like neuro-behavioural changes, liver abnormalities and kidney dysfunction. A study conducted by Lantin et al. (2010) had associated pesticide exposure to hormone disruption, allergies and hypersensitivity. Dahab et al. (2017) also proposed the possible associations between pesticide exposure and the prostate, ovarian and nervous system cancers. There is also a growing evidence on pesticides that may cause the developmental effects such as birth defects, reduced birth weight and fatal death (Baldi et al., 2011). Numerous studies have suggested effects from occupational exposure to endocrine disrupting pesticides on the reproductive system including reduced semen quality and lower luteinizing hormone (Mehrpour et al., 2014; Cremonese et al., 2017).

CHAPTER 3

MATERIALS AND METHODS

3.1 Study Area

This study was conducted at two paddy areas in two districts of Kelantan, namely Bukit Jawa (Fig 3.1) in Pasir Puteh and Bendang Keladi (Fig 3.2) in Tanah Merah. The paddy fields in Bukit Jawa was a granary area, which was under the management of Kemubu Agriculture Development Authority (KADA). The study area comprised of 4459 units of paddy rice lots with a total of 2724 hectare of paddy fields (Ministry of Agriculture & Agrobased Industry Malaysia, 2019). Meanwhile, Bendang Keladi was a non-granary area under the management of Department of Agriculture Tanah Merah.

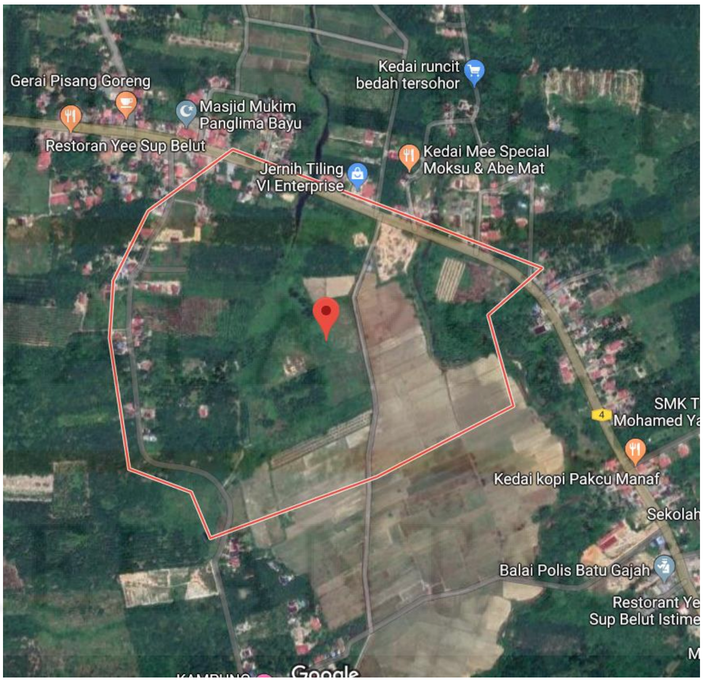

Figure 3.1: The study area at Bendang Keladi, Tanah Merah. (Source: Google Map)

Figure 3.2: The study area at Bukit Jawa, Pasir Puteh (Source: Google Map)

The paddy cropping seasons for Bukit Jawa was scheduled bi-seasonally by KADA, for which off-season (Season I) was between March to July while the main season (Season II) was between August and February (Ministry of Agriculture & Agrobased Industry Malaysia, 2019). For the paddy fields in Bendang Keladi, the cropping seasons were from July to October and February to May depending on the climate and irrigation system of the area.

3.2 Target Population

A total of 21 respondents were randomly selected to participate in pesticide survey via face-to-face interview and questionnaire survey, comprising 12 farmers from Pasir Puteh and nine farmers from Tanah Merah. All the selected paddy farmers were living nearby the paddy fields.

3.3 Data Collection

The data from this study was collected from July 2019 to October 2019 based on the paddy season of the study areas. Two major methods were used to collect basic information and pesticide data comprising surveys (personal interview and questionnaire) and the collection of pesticide packages. The data were collected at the end of each months to ensure the sufficiency of the data.

3.3.1 Interview and questionnaire

Surveys were conducted via face-to-face interview and questionnaire forms. The interview took approximately 20 minutes per respondent whereas the questionnaire survey required the selected farmers to fill in across the whole cropping season (approximately 3 months).

A field visit was conducted to assess the suitability of the questionnaire and obtaining the basic information of the paddy farmers who willingly involved in the surveys. Then, a section of face-to-face interview was held with the farmers before distributing them with the structured questionnaire forms. An informed consent (Appendix 1) was given to each farmer who volunteered to involve in this survey.

The face-to-face interview consisted of 6 parts of questions (Appendix 2); Part A is the demographic profile of the farmers (e.g age, education level and occupation), Part B is the information about pesticide uses (e.g. sources, pesticide's storage and health problems cause by the use of pesticides), Part C is about sprayer's information, Part D is the average time need for each pesticide activity, Part E is the average number of activities during pesticides application and Part F is about the use of personal protective equipment (PPE). The questionnaire form required the farmers to fill up pesticide information every time they applied pesticides (Appendix 3).

3.3.2 Collection of the pesticide labels

Each pesticide products have its own pesticide label including the trade or brand name, volume or weight of the product, name of active ingredients (AIs) and the respective concentrations. The collection of pesticides labels has been proved to be an effective and rapid assessment method to acquire some baseline information about pesticide application (Sattler et al., 2018). Therefore, the label of pesticide used by farmers were collected to extract the data obtained on the label. The collection of the pesticide labels were done on the end of each months of July 2019 to October 2019.

3.4 Data Analysis

3.4.1 Mathematical Exposure Model

In this study, mathematical exposure model developed by Wong et al. (2017) was used to estimate the exposure level of the selected downwind distances at 100 m from the edge of the field for each farmer. Assuming each product was applied on a single spraying day, the total pesticide exposure via inhaled vapour and indirect dermal contact with the contaminated ground were used predicted on a daily basis (mg kg $bw^{-1}day^{-1}$). This is followed by the sum of individual exposure estimates for the total aggregated exposures for individual farmers across the whole cropping season.

3.4.1.1 Pesticide volatilisation from treated surfaces (source emission)

For pesticide treated on the plant surface, the respective actual volatilisation rate is the mass of application per unit area of plant immediately after application, J_{plant} (g m^{-2} day^{-1}) (Equation 3.1).

$$J_{plant} = \left(\frac{C_{g,ps} - C_{air}}{r}\right) \times f_{mas} \tag{3.1}$$

where $C_{g,ps}$ is the saturated vapour concentration of active substance in the gas phase at the plant surface (g m^{-3}) that depends on the substance-specific vapour pressure at the prevailing temperature (van den Berg and Leistra, 2004) (Equation 3.2)

$$C_{g,ps} = \frac{M \times VP(T)}{R \times T} \tag{3.2}$$

where M is the molecular mass of the active substance (g mol^{-1}), $VP(T)$ is the vapour pressure (Pa) as a function of temperature based on PPDB (2019), R is the universal gas constant (Pa m^3 K^{-1} mol^{-1}), and T is the air temperature (K), C_{air} is the concentration in the turbulent air just outside the laminar air layer (gm^{-3}), r is the resistance to transport from plant surface to atmosphere calculated as the ratio of thickness of the boundary air layer, d (d m^{-1}) is the adjusted air diffusion coefficient, D_a (m^2 day^{-1}) and f_{mas} is the factor used to adjust amount of active substance present on the plants (Equation 3.3).

$$f_{mas} = \frac{A_p}{A_{p,ref}} \tag{3.3}$$

where A_p is the areic mass of pesticide on the plants (gm^{-2}) and $A_{p,ref}$ is the reference areic mass of pesticides on plants.

For pesticide applied on exposed soil surface, the respective volatilisation rate is the maximum daily emission of the mass of pesticide applied per unit area of soil immediately after application, J_{soil} (g m^{-2} day^{-1}) (Equation 3.4).

$$J_{soil} = \frac{H' c_{sol}}{r} \tag{3.4}$$

where H' is the non-dimensional Henry's law constant, r is the resistance to transport from the soil surface to the atmosphere (as calculated in Equation 3.1), c_{sol} is pesticide concentration in the soil pore water (g cm^{-3}) that depends on application rate and the substance specific organic carbon partition coefficient, K_{oc} (mL g^{-1}), with the use of default values for fraction of organic carbon, f_{oc}, soil water content (g g^{-1}), and dry soil bulk density (g cm^{-3}).

Adjustments are needed for three temperature-dependent parameters, namely D_a, H' and $VP(T)$. According to Leistra et al. (2001), D_a was adjusted with (Equation 3.5).

$$D_a = D_{a,ref} \times \left(\frac{T}{Tref}\right)^{1.75} \tag{3.5}$$

$D_{a,ref}$ is the active substance diffusion coefficient in air at 20 °C and T_{ref} is the reference temperature at 20 °C. H' was adjusted with a $Q10$ factor as the ratio of degradation rates between the rates at 20° and 10 °C (EFSA 2007). According to Sarigiannis et al. (2013) (Equation 3.6).

$$VP = VP_{ref} \exp\left[-\frac{\Delta H_{vap}}{R}\left(\frac{1}{T} - \frac{1}{Tref}\right)\right] \tag{3.6}$$

where VP_{ref} is the saturated vapour pressure of the substance at reference conditions (mPa), ΔH_{vap} is the molar enthalpy of evaporation (J mol^{-1}), R is the universal gas constant (J K^{-1} mol^{-1}), T is the air temperature (K), and T_{ref} is the reference air temperature (K).

Finally, the total area source emission rate is the sum of actual volatilisation from the plant and soil surfaces, $Q_{act,}$ (g m^{-2} s^{-1}) (Equation 3.7).

$$Q_{act} = \frac{(Jplant + Jsoil)}{86{,}400} \tag{3.7}$$

where 86,400 converts the units of time from days to seconds.

3.4.1.2 Dispersion of volatilised pesticides downwind

The total estimated volatilisation rate for single active substances from both treated plant and soil surfaces was translated into airborne pesticide concentration at 100 m downwind to the treated field, X (m) (Equation 3.8).

$$X = \frac{Q_{act} \times V \times E \times X_o}{4 \times \sqrt{2} \times U_s \times \sigma_z} \tag{3.8}$$

where Q_{act} is the area source emission rate (gm^{-2} s^{-1}), V is the vertical term (−), E is the error function term (−), X_0 is the length of the side of the square area source (m), U_s is the wind speed (m s^{-1}), and σ_z is the vertical standard deviation (−),

V was required to change the form of the vertical concentration distribution from Gaussian to rectangular (uniform concentration within the surface mixing layer) at the selected downwind distance (Equation 3.9).

$$V = \exp\left[-0.5\left(\frac{zr-he}{\sigma z}\right)^2\right] + \left[-0.5\,\frac{zr+(2izi-he)}{\sigma z}\right)^2 +$$
$$\sum_{i=1}^{\infty}\{\exp\left[-0.5\left(\frac{zr-(2izi-he)}{\sigma z}\right)^2\right] + \exp\left[-0.5\left(\frac{zr+(2izi-he)}{\sigma z}\right)^2\right] +$$
$$\exp\left[-0.5\left(\frac{zr-(2izi+he)}{\sigma z}\right]^2 + \exp\left[-0.5\left(\frac{zr+(2izi+he)}{\sigma z}\right)\right]^2\} \tag{3.9}$$

where h_e is the crop height (m), z_r is adult height above ground (m) and z_i is the mixing height (m) adjusted based on crop height (Randerson, 1984) (Equation 3.10).

$$zi = \frac{0.3u*}{f} \tag{3.10}$$

where f is the Coriolis parameter (s^{-1} at 40° latitude) and u_* is friction velocity (m s^{-1}) calculated for the reference wind speed, *u(z)* at 2.0 m above the ground using the logarithmic wind profile relationship (Equation 3.11).

$$u(z) = \frac{u*}{k} \ln\left(\frac{z}{z_0}\right) \tag{3.11}$$

where k is the von Karman's constant (dimensionless) and $z_0$is the roughness parameter (m) approximated as 10% of the height of the crop surface.

The error function term, E is calculated as in (Equation 3.12).

$$E = \mathrm{erf}\left(\frac{r0+y}{\sqrt{2\sigma y}}\right) + \mathrm{erf}\left(\frac{r0-y}{\sqrt{2\sigma y}}\right) \tag{3.12}$$

where r_o' is the effective radius of area source $\frac{X_0}{\sqrt{\pi}}$ (m) and σ_y is the lateral vertical standard deviation.

The dispersion parameters were calculated according to a power law fit to wind tunnel data (US EPA) (Equation 3.13).

$$\sigma y = 0.73547X^{0.64931} \tag{3.13}$$

$$\sigma z = 0.28565X^{0.71285} \tag{3.14}$$

3.4.1.3 Calculation of inhalation exposure

SER_I is the systemic exposure of residents via the inhalation route (mg kg bw^{-1} day^{-1}), VC is the estimated pesticide vapour concentration (mg m^{-3}) at the selected proximity, IR is inhalation rate (m^3 day^{-1}), IA is inhalation absorption (−) and BW is body weight (kg) (Equation 3.15).

$$SER_I = \frac{VC.IR.A}{BW} \tag{3.15}$$

3.4.1.4 Calculation of indirect dermal exposure

Systemic exposure via the dermal route, SER_D (mg kg bw^{-1} day^{-1}) was calculated according to EFSA (2014) (Equation 3.16).

$$SER_D = \frac{AR.D.TTR.TC.H.DA}{BW} \tag{3.16}$$

where *AR* is the application rate (mg cm^{-2}), *TTR* is the turf transferable residue (−), *TC* is the transfer coefficient (cm^2 h^{-1}), *H* is the exposure duration (hour), *DA* is the dermal absorption (−), and *BW* is the body weight (kg). *D* is the drift fraction which is calculated in accordance with crop growth stages (Equation 3.17) (Equation 3.18) and (Equation 3.19).

$$For\ early\ growth\ stages, D = \left(\frac{3908.3^{*}(X^{-2.421})}{100}\right) \tag{3.17}$$

$$For\ late\ growth\ stages, D = \left(\frac{298.83^{*}(X^{-1.8672})}{100}\right) \tag{3.18}$$

$$For\ downward\ herbicide\ application, D$$
$$= 2.7705^{*}(X^{-0.9787}) \tag{3.19}$$

where *X* is the selected downwind distance (m).

3.4.1.4 Calculation of total exposure

The estimated levels of exposure to individual active substances via the two identified routes of exposure were summed up to give a total exposure (mg kg bw^{-1} day^{-1}) (Equation 3.20).

$$\sum Exposure(AS) = Exposure(Inhaled\ vapour) + Exposure(Indirect\ dermal) \tag{3.20}$$

Finally, the total daily exposures to individual active substances were summed to give an aggregated exposure during the entire cropping season (Equation 3.21).

$$\sum Aggregated\ exposure = Exposure(ASi) + \cdots + Exposure(ASi + n) \tag{3.21}$$

3.4.2 Risk Estimation

Based on the hazard quotient (HQ) approach, the predicted exposure was then be assessed against the no observed (adverse) effect levels (NO(A)ELs) for reproductive/developmental effects as the reference point (Equation 3.22).

$$HQ = \frac{Sum\ of\ exposure\ estimates\ for\ an\ active\ substance}{Reference\ point} \tag{3.22}$$

The NO(A)ELs were extracted from four established toxicological databases, namely EFSA Draft Assessment Reports (DARs) and Renewal Assessment Reports (RARs), Joint Meeting on Pesticide Residues (JMPR) of the International Programme on Chemical Safety (IPCS INCHEM), Integrated Risk Information System (IRIS) and Hazardous Substances Data Bank (HSDB) in the Toxicology Data Network (TOXNET) (Wong et al., 2017). Risk is considered acceptable if calculated HQ values ≤ 1 (Stein et al., 2014).

CHAPTER 4

RESULT AND DISCUSSION

4.1 Farmers Basic Information

Table 4.1 shows all the respondents were male with their age ranged from 21 to 70 years old; nine farmers under the age of 40 years old, 8 farmers aged between 41 and 60 years old and 4 farmers aged greater than 61 years old. Overall, six farmers had training certificate (theory and practical) that were organised by Kemubu Agriculture Development Authority (KADA), for which five of them with age larger than 55 years old. The training can provide basic knowledge and information for paddy pest management to the farmers. All respondents were full-time worker at the paddy fields.

In this study, respondents were required to record every pesticide usage across the cropping season between 90 to 120 days. However, in this study, only 10 out of 21 respondents completed the survey (TM01, TM02, TM03, TM04, TM05, TM06, TM07, PP01, PP02 and PP03) and their data were analysed further below.

Table 4.1: The basic information of the farmers

Farmers	Age	Gender	Spraying Experience	Training Certificate
TM01	38	M	10	No
TM02	27	M	2	No
TM03	56	M	27	Yes
TM04	53	M	2	No
TM05	47	M	6	No

Table 4.1 (Continued)

Farmers	Age	Gender	Spraying Experience	Training Certification
TM06	25	M	4	No
TM07	60	M	5	No
TM08	39	M	8	No
TM09	57	M	10	Yes
PP01	59	M	20	Yes
PP02	64	M	45	Yes
PP03	29	M	12	Yes
PP04	41	M	11	No
PP05	25	M	8	No
PP06	27	M	5	No
PP07	67	M	34	Yes
PP08	29	M	10	No
PP09	21	M	3	No
PP10	69	M	10	No
PP11	70	M	50	No
PP12	55	M	10	No

Figure 4.1 shows poor relationship between the age of farmers and their working experience in agriculture (R^2: 0.40). Nevertheless, study have shown that age and working experience are influential factors towards farmers' exposure to pesticides because farmers that been in the field tend to expose from cumulative exposure throughout their working life as compared to young farmer that have less working experience in the field (How et al., 2013).

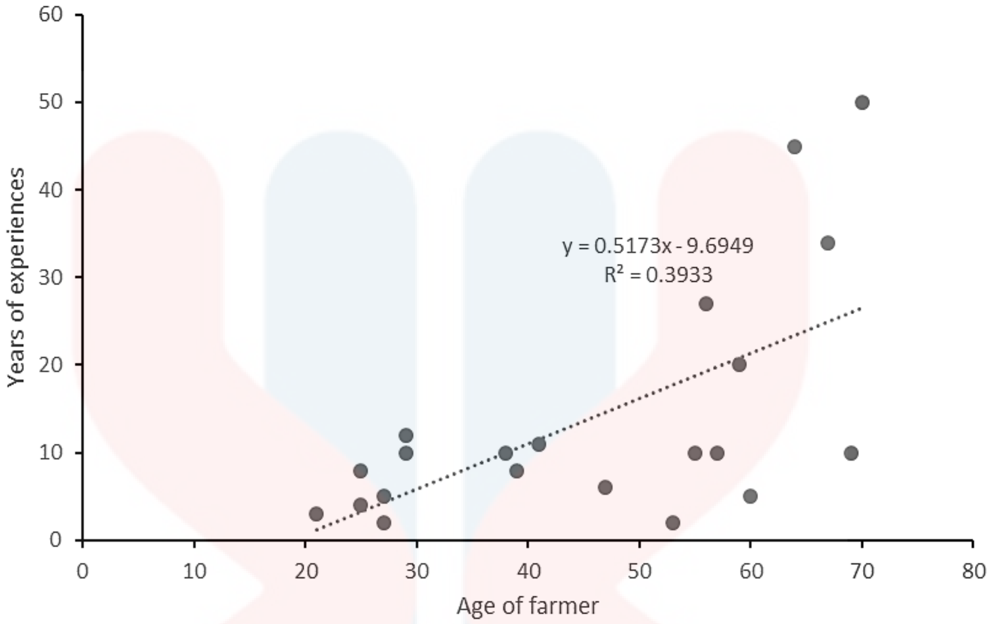

Figure 4.1: Relationship between years of farming experiences and the age of farmers

4.2 Pesticide Data

4.2.1 Pesticide Application

Figure 4.2 shows the application rate of single active substances applied to the total grown area by each farmer during the cropping season. The total amount of pesticide applied varied between each farmer ranged from 0.13 to 12.14 kg ha^{-1}. Half of the ten selected farmers had application rates less than 1.0 kg ha^{-1} while the rest had application rates up to 2 kg ha^{-1}. The application rate of 7 of the farmers were lower than the total grown area but 3 of the farmers use pesticide over their grown area. For example, there was a farmer (TM07) with the highest application rate with a small grown area (4 ha) due to the excess use of pesticide in a treated area. According to Parveen et al. (2001), farmers tend to use pesticides such as insecticides up to 5 or 6 times in one cropping season, which is more frequent than the recommended application rate and they may apply pesticides at wrong doses, methods and times for a better rice production. Typically, the application rate mainly depends on the type and amount of active substances used in each treated area.

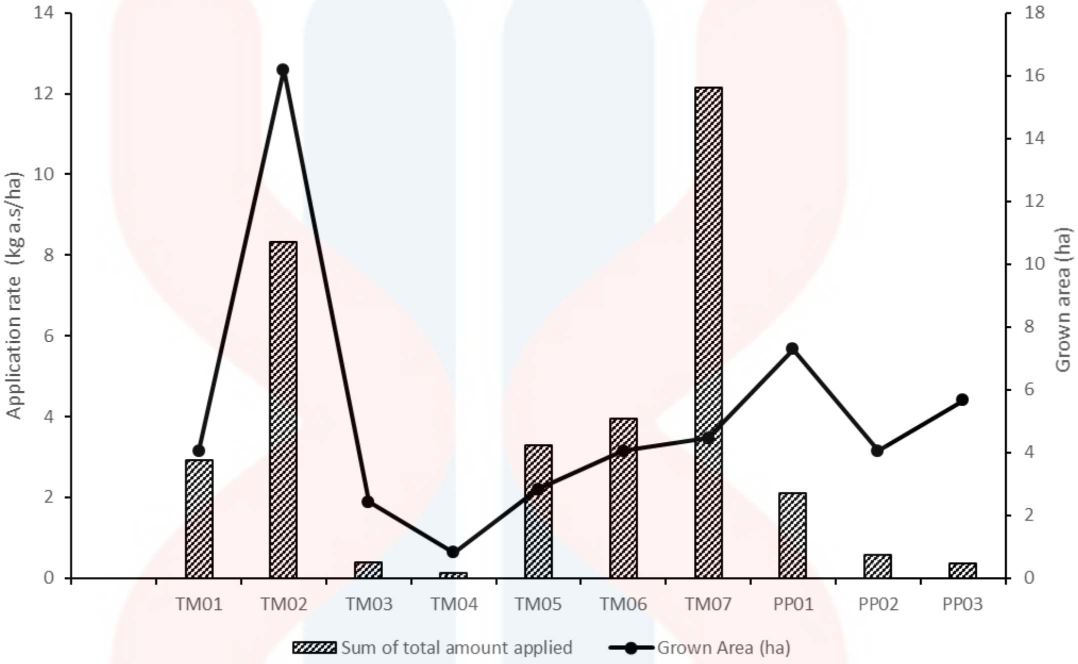

Figure 4.2: Application rate of pesticides to the total grown area for the 10 selected farmers across the whole cropping season

4.2.2 Type of Pesticides

Figure 4.3 shows the total number of pesticide products based on three major pesticide types (fungicide, herbicide and insecticide) applied by individual farmers. Overall, insecticides were the most commonly applied pesticides (3 - 8 products), followed by herbicides (1 – 4 products) and fungicides (up to 2 products) among the selected farmers. This is supported by Tandi et al. (2014) and Tambe et al. (2019) that the most frequently used pesticide was insecticide. Herbicides were mainly use before the reproductive phase of the cropping to avoid the growth of grasses and disturb the ripening phase.

Farmer (TM07) use a high total number of pesticide product (14 products) used, that also influence the amount of application rate in Fig 4.2 as it increases the number of active substances. A pesticide product might consist more than 1 active substances thus it increases the application rate of the farmer.

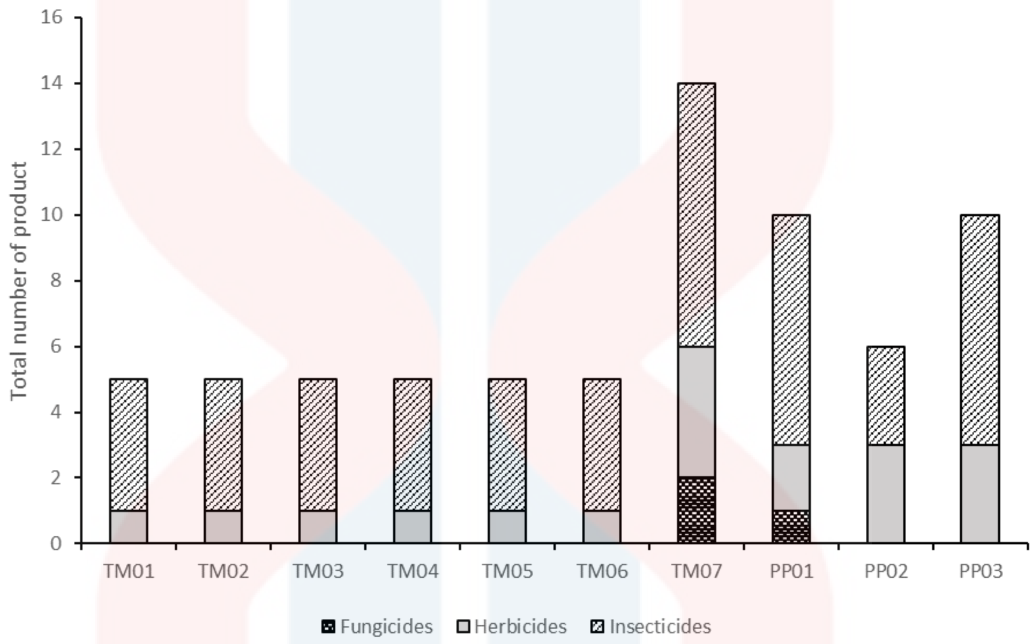

Figure 4.3: Classification of pesticide products based on three major pesticide types that applied by the selected farmers

4.2.3 Active substances

Figure 4.4 presents the data of the number of active substances used by farmer within the cropping season that started from July to October 2019. Generally, the farmers used the same type of pesticide products but at different application timings. There was a large difference on the total number of active substances used by farmers during the season, corresponding to the total number of products applied by the farmers (Fig. 4.3). Farmer (TM07) had the highest active substances value mainly due to the higher number of pesticides products used namely insecticides and herbicides. Therefore, farmer that used many types of pesticides tend to have high number of active substances value.

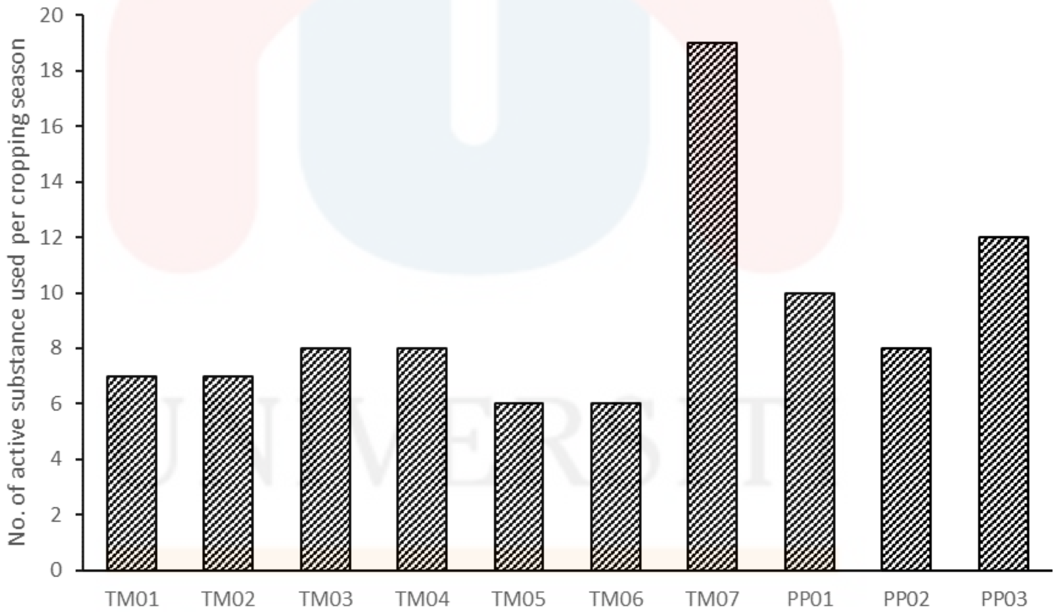

Figure 4.4: Total number of active substances used by the selected farmers across a cropping season

Figures 4.5(a) and 4.5(b) show the vapour pressures of active substances between approved and not approved status in accordance with the Pesticide Properties Database (PPDB, 2019).

Out of 30 active substances enlisted, 16 were not approved for their use in the European Union in accordance with the PPDB. Five active substances from the list namely fenobucarb (48 mPa), thiobencarb (2.39 mPa), fentin acetate (1.9 mPa), chlorpyrifos (1.43 mPa) and pretilachlor (0.13 mPa) have relatively higher vapour pressure that possibly increased their volatilization rate and thus exposure level (VP > 0.13 mPa). Ahmed et al. (2012) proposed that pretilachlor was a common herbicide that the toxic effect on various animal cells were proven supported by Hamsan et al. (2018) that pretilachlor could affect most of the self-reported respiratory health symptoms. The study indicates most active substances that were not approved were herbicides, including ethoxysulfuron, fentin acetate, imazapic, imazapyr, pretilachlor, propanil, pyribenzoxim and thiobencarb. Active substances with higher vapour pressure may lead to increased vapour inhalation exposure. This is because volatile pesticides tend to lost rapidly with increasing temperatures and rapidly volatilize right after the application (Abdullah et al., 1997; Hanson et al., 2016).

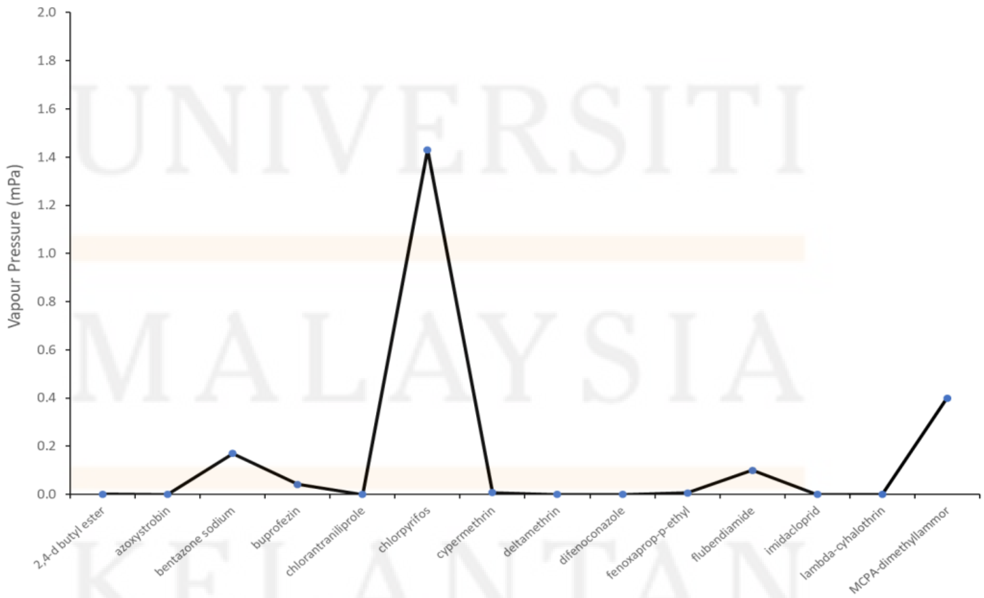

Figure 4.5 (a): Vapour pressures for the 14 approved active substances in accordance with the PPDB (2019)

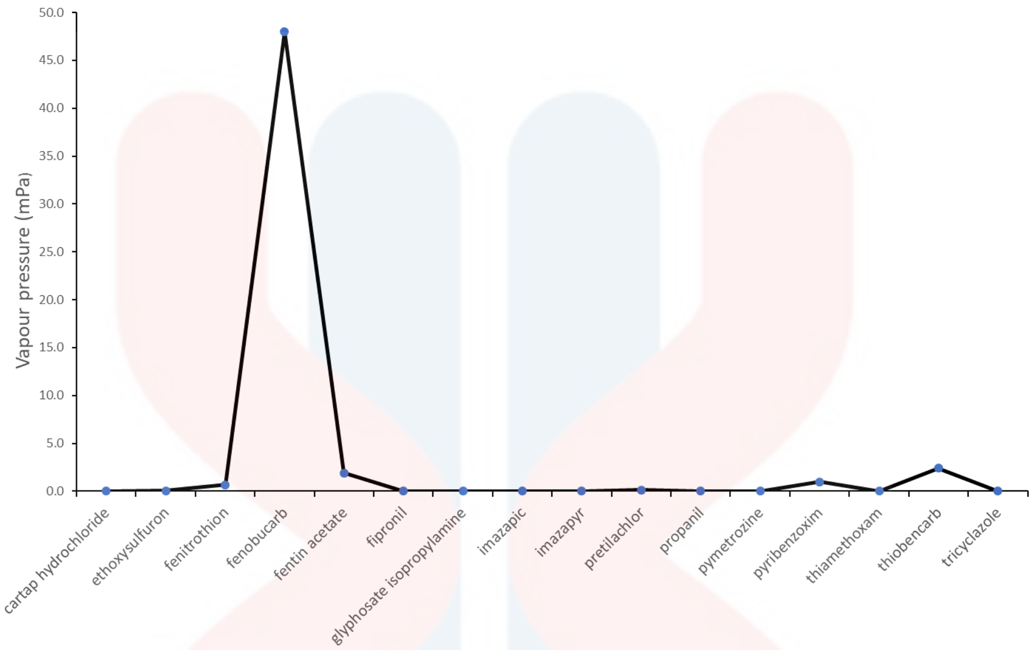

Figure 4.5 (b): Vapour pressures of the 16 not approved active substances based on the PPDB (2019)

Figures 4.6(a) and 4.6(b) show the values of no observe (adverse) effect level (NO(A)EL of single active substances that were approved and not approved for their use in the European Union, with larger NO(A)EL value indicates lower toxicity. Among the approved list of active substances, flubendiamide have the largest NO(A)EL value of 1000 mg kg bw^{-1} day^{-1} compared to 11 others active substances that less than 200 mg kg bw^{-1} day^{-1} (Fig 4.6(a)). On the other hand, imazapic and imazapyr have the NO(A)EL values of 1000 mg kg bw^{-1} day^{-1} for the not approved active substances with seven active substances have the value less than 200 mg kg bw^{-1} day^{-1} (Fig 4.6(b)). However, 5 active substances from the not approved list have no available data of NO(A)EL.

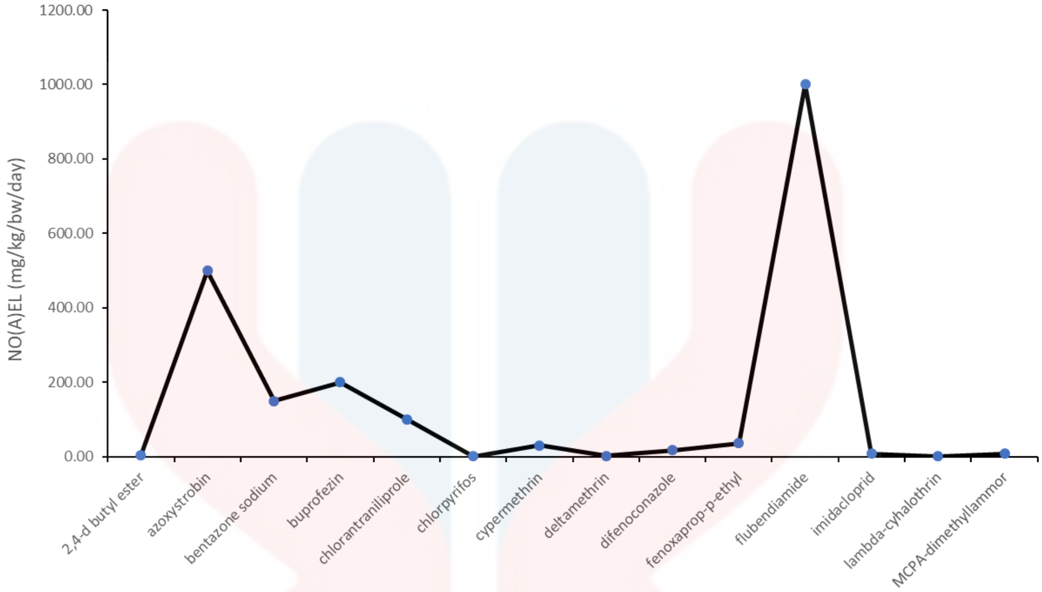

Figure 4.6 (a): NO(A)EL of the approved active substances

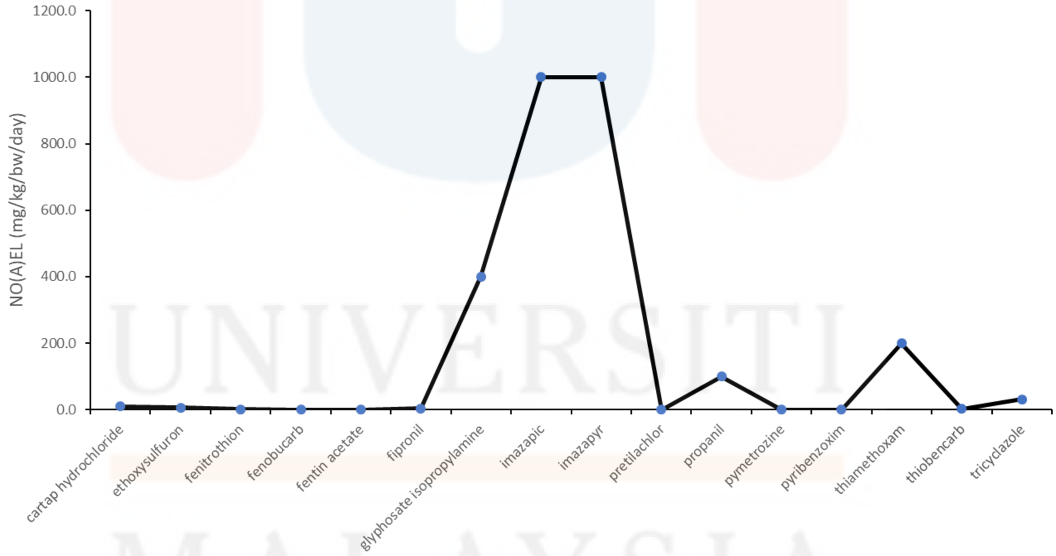

Figure 4.6 (b): NO(A)EL of the not approved active substances

4.3 Risk Estimation

4.3.1 Exposure Level

Figure 4.7(a) shows the aggregated exposure of herbicides, insecticides and fungicides for individual farmers living at 100 m downwind. Overall, farmers have relatively larger total aggregated exposure to herbicides ($6.87 \times 10^{-3} – 1.06 \times 10^{-3}$ mg kg bw^{-1} day^{-1}), intermediate for insecticides ($1.91 \times 10^{-4} – 3.21 \times 10^{-6}$ mg kg bw^{-1} day^{-1}) and lowest for fungicides. That is, farmers had relatively higher herbicide exposure (4.29 – 98.28 % of total aggregated exposure), followed by insecticides (1.54 – 95.8 %) and the least for fungicides (0.01-0.16 %) (Fig. 4.7 (b)). Generally, the levels of exposure were dependent on the total amount of pesticide products and the concentration of active substances applied by individual farmers.

As from the result, TM07 has the highest exposure compared to other farmer as it had the highest total number of active substances (xx compounds; Fig 4.4) that were influenced by the respective vapour pressures. That is, high exposure level of farmer TM07 were mainly caused by the inhalation of the pesticide that volatize rapidly, for instance, fenobucarb (48 mPa) and thiobencarb (2.39 mPa) were common pesticides used by the farmer that have high vaporisation value that cause high total exposure to the farmer.

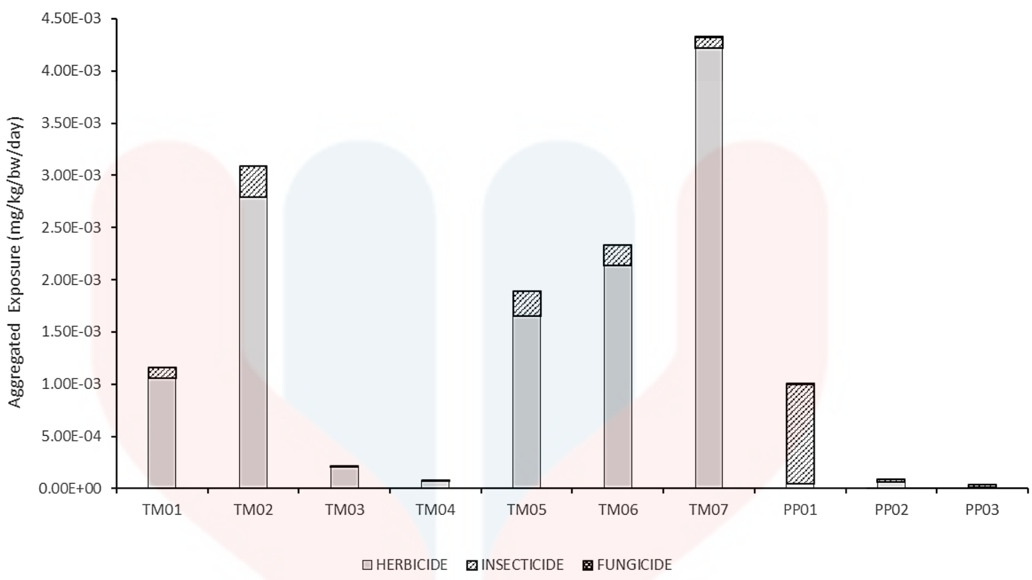

Figure 4.7 (a): Total aggregated exposures for the selected farmers living at 100 m downwind

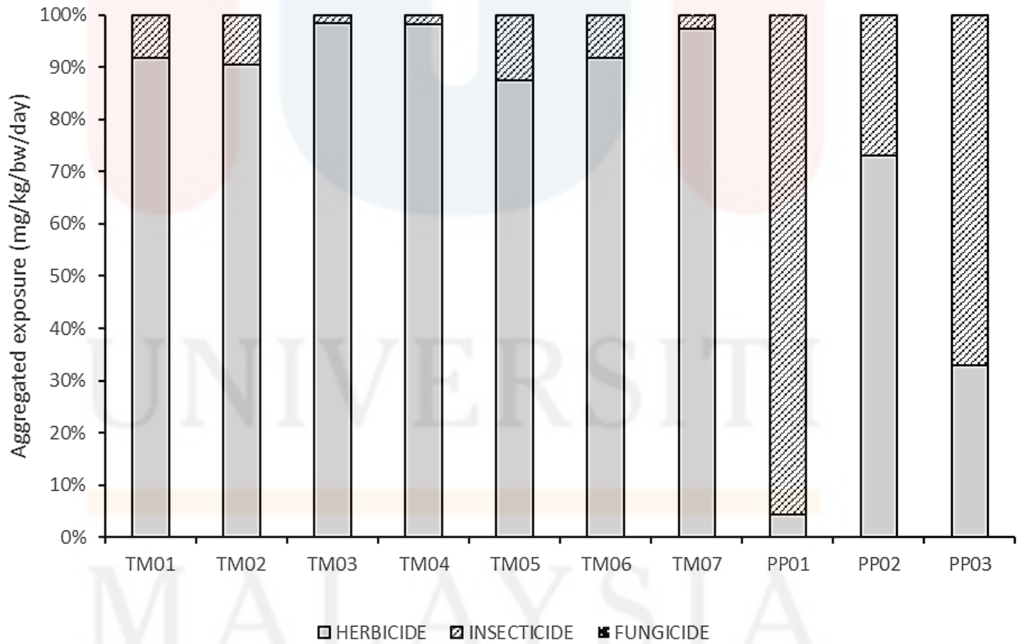

Figure 4.7 (b): Percentage of total aggregated exposures for farmers living at 100 m downwind

Figure 4.8 shows the majority of the farmers were exposed to pesticides via inhaled vapour with the highest exposure was 3.69×10^{-3} mg kg bw^{-1} day^{-1} and the lowest was 5.91×10^{-6} mg kg bw^{-1} day^{-1}. Choi et al. (2013) proposed that the inhalation vapour was higher during the mixing/loading activities but relatively lower in total exposure due to shorter working time. The indirect dermal exposure was comparatively lower than inhaled vapour exposure with the highest exposure was 6.43×10^{-6} mg kg bw^{-1} day^{-1} and the lowest was 1.97×10^{-6} mg kg bw^{-1} day^{-1}.

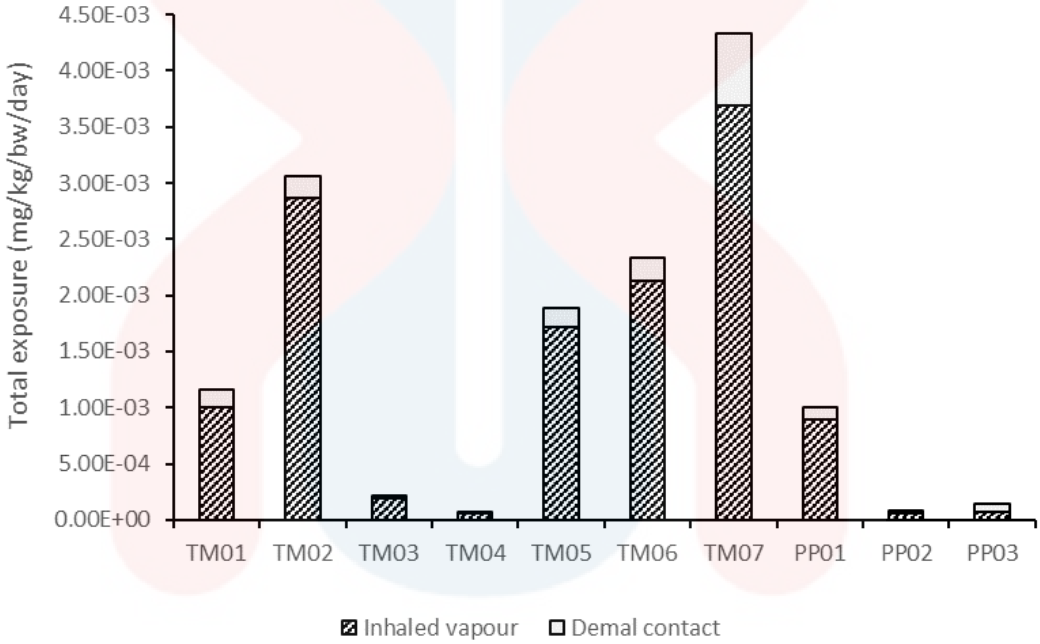

Figure 4.8: Aggregated inhaled vapour and dermal contact of each farmer

Overall, the aggregated exposures were influenced by the inhaled pesticide vapour that in turn dependent on airborne concentration at different proximities, inhalation rate and inhalation adsorption per body weight of the farmer whereas indirect dermal exposures were influenced by the application rate, turf transferable residue, transfer coefficient, exposure duration and dermal adsorption to the body weight of farmer based on the model's assumptions.

4.3.2 Hazard Quotients

Figure 4.9(a) shows the comparison of HQs between pesticide types for the ten selected farmers at 100 m downwind from the edge of paddy field. The aggregated hazard quotients were different among the farmers ranged from 1.85×10^{-6} to 1.64×10^{-3}). Figure 4.9(b) indicates herbicides contributed to relatively larger average percentage of total aggregated exposure (0.92 – 99.48%), followed by insecticides (0.52 – 99.08 %) and fungicides (0.001 – 0.036%). Overall, all aggregated HQs were less than 1 indicating the adverse reproductive/developmental effects were not significant among the selected farmers.

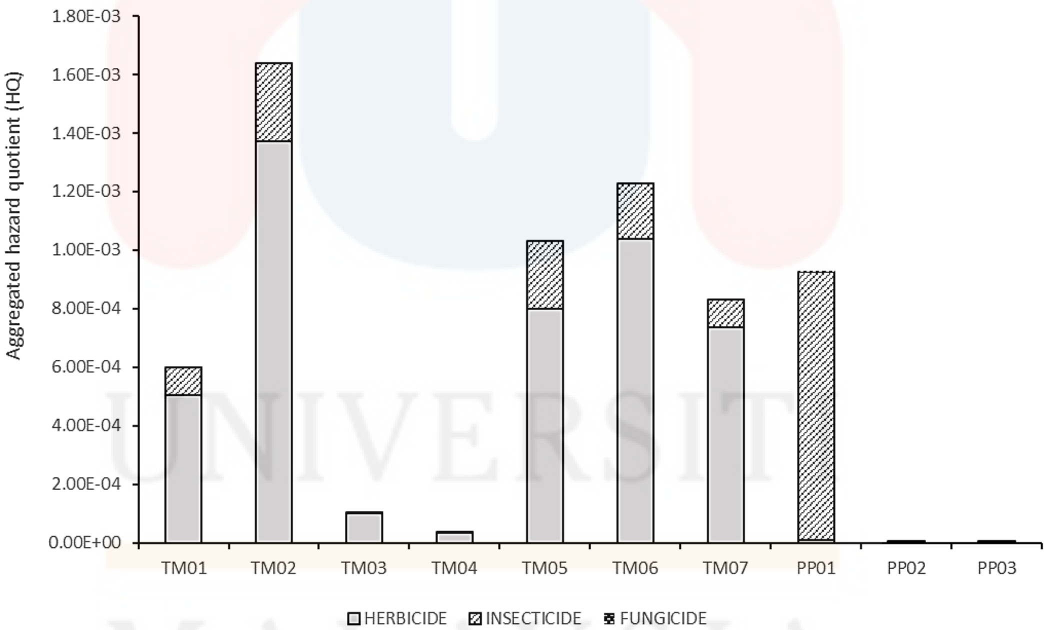

Figure 4.9 (a): Aggregated hazard quotients for the reproductive/developmental effects based on three major types of pesticides applied by the selected farmers for pesticide exposure at proximity of 100 m downwind

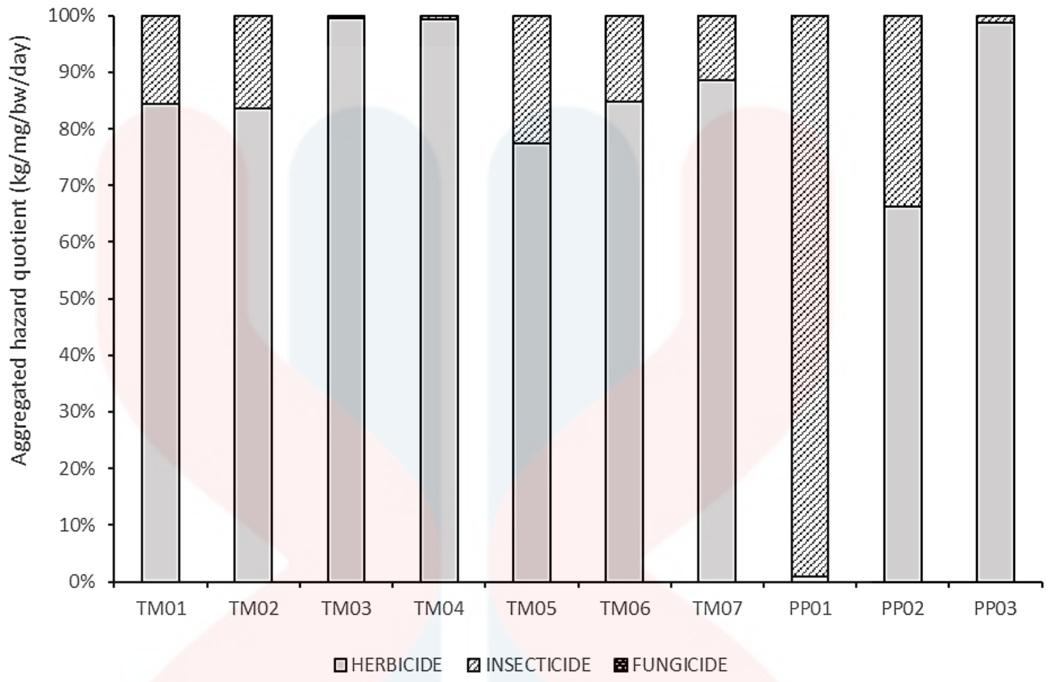

Figure 4.9 (b): Percentage of aggregated hazard quotients for the reproductive/developmental effects based on three major types of pesticides applied by the selected farmers for pesticide exposure at proximity of 100 m downwind

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusions

This study identifies the environmental exposure of paddy farmers to pesticide drifts based on the amount and type of pesticides applied in the nearby paddy fields, assuming they living at 100 m distances downwind from the fields. Results show that total exposure of each farmers had larger inhalation exposure compared to indirect dermal exposure based on the model's assumptions. Overall, the number of insecticide products used was highest, but herbicides contributed to the highest level of aggregated exposure and aggregated HQ, mainly due to the relatively higher vapour pressures of herbicides active substances. In this study, the calculated HQs were less than 1, indicating that the developmental/reproductive effects are not of significant health concern.

5.2 Recommendations

In this study, a predefined distance of 100 m downwind from the edge of paddy field was selected, with the future study is recommended to use the exact distance of the farmers' living area to the paddy field for improved accuracy of exposure quantification and risk characterization of paddy farmers living nearby the paddy fields. Besides, this study identifies the use of some pesticide active substances that are not approved by the developed countries like the European Union based on the international Pesticide Properties Database (PPDB), mainly due to the inherent toxicity of these pesticides. Therefore, local authorities and government should review the existing pesticides in the local market and regulate the production, sale and use of both old and new products, and make the pesticide data publicly available. Monitoring of the pesticides in the market on a regular basis is important as farmers tend to use banned pesticides that are more effective and cheaper for their crop production. Government should also enforce the law of pesticide production and use, including the removal of pesticides that have been withdrawn in the developed countries due to their more hazardous properties.

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APPENDICES

APPENDIC 1

BORANG PERSETUJUAN TERMAKLUM (INFORMED CONSENT)

Dengan segala hormatnya,

Saya seperti yang tertera merupakan mahasiswa Fakulti Sains Bumi bagi program Sains Gunaan Sains Kelestarian di Universiti Malaysia Kelantan Kampus Jeli:

Nama : An Nurainee binti Jais

No. Kad Pengenalan : 970902015584

Tujuan persetujuan termaklum ini adalah bagi mengadakan penyelidikan berkenaan projek akhir tahun berjudul **"Penilaian Pendedahan Racun Perosak terhadap Petani yang Tinggal Berhampiran Sawah Padi"**. Penyelidikan ini adalah bagi menilai tahap/jumlah pendedahan racun perosak terhadap petani pada jarak tertentu dan menyelidik bagaimana pendedahan racun perosak adalah berbeza-beza sewaktu musim penanaman. Dengan jayanya kajian ini dapat menyumbang kepada pengetahuan saintifik yang lebih meluas terhadap kesan dan risiko penggunaan racun perosak.

Bagi melaksanakan penyelidikan ini, saya memerlukan kesediaan pihak tuan/puan untuk mengambil bahagian dalam penyelidikan ini sebagai responden dengan mengisi borang soal selidik dan kaji selidik serta bersedia untuk ditemubual. Setiap jawapan yang diberikan adalah sulit dan di bawah tanggungjawab saya namun responden berhak untuk mengetahui rekod soal selidik reponden sendiri. Maklumat yang diperolehi hanya akan digunakan bagi tujuan penyelidikan ini. Jangkauan tempoh waktu yang diperlukan bagi setiap responden adalah 20 minit bagi temubual dan 3 bulan (tempoh penanaman) bagi borang kaji selidik.

Penyertaan sebagai responden adalah sukarela dan responden berhak untuk menarik diri daripada kajian pada bila-bila masa tanpa sebarang tindakan. Jika tuan/puan bersetuju untuk mengambil bahagian dalam penyelidikan ini, diharap pihak tuan/puan dapat menandatangani borang persetujuan termaklum (informed consent) di lampiran berikutnya.

Kerjasama daripada tuan/puan untuk mengambil bahagian dalam penyelidikan ini amatlah dihargai. Sekian, terima kasih.

Saya selaku responden yang tertera:

Nama : ____

Umur : ____

Jantina : ____

Alamat : ____

____

Pekerjaan : ____

Dengan ini bersedia untuk menjadi reponden bagi penyelidikan yang dilakukan oleh An Nurainee binti Jais (970902015584), mahasiswa Fakulti Sains Bumi bagi Program Sains Gunaan Sains Kelestarian, Universiti Malaysia Kelantan Kampus Jeli yang berjudul **"Penilaian Pendedahan Racun Perosak terhadap Petani yang Tinggal Berhampiran Sawah Padi"**. Saya telah membaca dan memahami kandungan dokumen ini bahawa penyelidikan ini tidak akan memberi kesan negatif terhadap diri saya, oleh itu saya bersedia untuk menjadi responden bagi penyelidikan ini.

Tarikh: ____________________

_____________________________ _____________________________

(Tandatangan Responden) (Tandatangan Penyelidik)

APPENDIC 2

Nama Kampung: Nama Daerah:

(A) Maklumat pesawah padi	
1. Nama:	2. Koordinat GPS (rumah):
3. No. telefon:	4. Jantina:
5. Umur:	6. Berat badan (kg):
7. Taraf pendidikan (bulatkan yang berkenaan): ○ Sekolah rendah / Sekolah menengah / Kolej / Universiti / Tidak pernah bersekolah	
8. Bekerja sebagai: ○ Pesawah padi sepenuh masa ○ Kerja sambilan (sila nyatakan): ____________________	
9. Pengalaman bekerja sebagai pesawah padi: _________ tahun	
10. Kursus/latihan: i. Tahun terkini menghadiri kursus/latihan: ________________ ii. Kursus/latihan dianjur oleh: ____________________ iii. Jenis kursus yang dihadiri: Theori / Praktikal / Kedua-duanya	
(B) Maklumat racun perosak	
1. Sumber racun:	2. Tempat simpan racun:

3. Aktiviti *mixing/loading:*

    i. Tempat campur racun:

    ____

    ii. Penggunaan penyukat waktu campur: Ada / Tiada

4. Cara pelupusan bekas kosong racun:

5. Masalah kesihatan yang disebabkan racun:

    i. Nyatakan jenis penyakit:

    ____

    ii. Cara sembuh:

    ____

(C) Maklumat mesin penyembur racun

1. Jenis penyembur (bilangan tahun):

    ○ Manual knapsack: ________ tahun

    ○ Motorised knapsack: ________ tahun

    ○ Lain (nyatakan):

    ____ tahun

2. Nama model mesin:	3. Kapasiti tangki (Liter):

4. Tempat simpan mesin:

(D) Purata masa diperlukan untuk aktiviti:

1. *Mixing/loading* (min/day):
2. *Spraying* (min/day):
3. *Cleaning sprayer* (min/day):

(E) Purata bilangan aktiviti dijalankan pada hari pakai racun:
1. *Mixing/loading* (no. of activity/day): 2. *Spraying* (no. of activity/day): 3. *Cleaning sprayer* (no. of activity/day):
(F) Penggunaan PPE
1. *Mixing/loading activit*y (bulatkan yang berkenaan): i. Tangan: sarung tangan kain / sarung tangan plastik / tidak memakai ii. Badan: baju lengan panjang / baju lengan pendek / seluar panjang / seluar pendek /apron iii. Kaki: kasut but / kasut getah / tidak memakai iv. Hidung: topeng kain atau kapas / topeng buatan sendiri / tidak memakai
2. *Spraying activity* (bulatkan yang berkenaan): i. Tangan: sarung tangan kain / sarung tangan plastik / tidak memakai ii. Badan: baju lengan panjang / baju lengan pendek / seluar panjang / seluar pendek /apron iii. Kaki: kasut but / kasut getah / tidak memakai iv. Hidung: topeng kain atau kapas / topeng buatan sendiri / tidak memakai
3. Sprayer cleaning (bulatkan yang berkenaan): i. Tangan: sarung tangan kain / sarung tangan plastik / tidak memakai ii. Badan: baju lengan panjang / baju lengan pendek / seluar panjang / seluar pendek /apron iii. Kaki: kasut but / kasut getah / tidak memakai iv. Hidung: topeng kain atau kapas / topeng buatan sendiri / tidak memakai
4. Berapa kali guna PPE sebelum dilupuskan? Jelaskan:

APPENDIC 3

Maklumat penggunaan racun pada hari berkenaan.

Tarikh	Jenama racun	Perosak	Pengeluar racun	Perumusan	Jumlah racun guna	Keluasan tanah disembur