THE FATE OF DIURON IN SOIL IN A MALAYSIAN OIL PALM PLANTATION

HALIMAH MUHAMAD*; MOHD IZWARIE RAMLI**; ZURIATI ZAKARIA‡ and ISMAIL SAHID‡‡

INTRODUCTION

Malaysia was the largest exporter (2010-2011) of palm oil in the world (MPOB, 2011). In 2011, the cultivated area of oil palm in Malaysia was approximately 5.00 million hectares. Total exports of palm oil products in 2011 were 24.27 million tonnes compared to 23.06 million tonnes in 2010 (MPOB, 2012). Normally in agricultural crops, yield can be affected by weeds that compete for nutrients, water and sunlight (Muhamed et al., 2009). Therefore, efforts to control weeds in oil palm plantations constitute a major activity. Herbicides such as diuron have been used in oil palm plantations as an alternative method of weed control (Ainie et al., 2007).

Diuron is widely used as a selective pre- and post-emergence herbicide for the control of most broad-leaved weeds and annual grasses (Ainie et al., 2007; Mou et al., 2008). Diuron is commonly used in oil palm plantations where weeds such as grasses (Paspalum conjugatum and Ottochloa nodosa), broad-leaf weeds (Asystasia intrusa and Cleome rutidosperma), legumes (Desmodium triflorum and Mimosa pudica) and ferns (Lygodium flexuosum and Nephrolepis biserrata) are found (Wahab, 2001; Ainie et al., 2007). Diuron belongs to the phenylurea group of herbicides that kills plants by blocking electron transport at photosystem II, thus inhibiting
photosynthesis. Diuron is absorbed principally through the roots and is a broad spectrum herbicide killing both broad-leaf and grassy weeds.

Diuron is the common name for 3-(3,4-dichlorophenyl)-1,1-dimethyl urea (C₈H₈Cl₂N₂O₂). Diuron is relatively stable in the environment, however, it can be hydrolysed under acidic and alkaline conditions or at high temperatures. It has a low solubility in water (42 mg litre⁻¹) at 25°C and a high adsorption rate onto the soil particles (Koc = 418 – 560). This pesticide has a low n-octanol-water partition coefficient (log Kow), of around 2.87 (Kidd and James, 1991; Goody et al., 2002; Lesueur et al., 2008). Therefore, it can be regarded as being highly persistent in the soil and poses a risk to water bodies and sediments through leaching processes. Despite its benefits in increasing agricultural production, diuron can have a negative impact on the environment.

The sorption, behaviour and fate of diuron in the environment has been extensively studied by many researchers (Goody et al., 2002; Adriana, 2004; Chefetz et al., 2004; Giacomazzi and Cochet, 2004; Lanyi and Dinya, 2005; Liyanage et al., 2006; Cabrera et al., 2007). The studies on the persistence, behaviour and fate of other pesticides in oil palm plantations, such as fluroxypyr (Halimah et al., 2005), chlorpyrifos (Halimah et al., 2010a), thiram (Maznah et al., 2010), fluroxypyr-MHE (Halimah et al., 2010b), carbofuran (Farahani et al., 2008) and cypermethrin, deltamethrin and endosulfan (Cheah et al., 2001) have been carried out. However, no study has been undertaken on the downward movement and persistence of diuron in oil palm plantations of Malaysia. This article presents results on the study to determine the downward movement and half-life of diuron in an oil palm plantation.

MATERIALS AND METHODS

Reagent and Chemicals

Methanol of high pressure liquid chromatography (HPLC) grade, acetonitrile, ethyl acetate and cyclohexane were obtained from Merck, Germany. Water, obtained from a Mili-Q water purification system (Millipore Corp., USA) was used to prepare the mobile phase. Standard diuron was purchased from the Laboratories of Dr Ehrenstorfer, Augsburg, Germany and sodium chloride was purchased from Merck.

Apparatus

The micro litre pipettes, adjustable between 100 and 1000 µl and pipette tips were obtained from Eppendorf (Hamburg, Germany) and the vortex mixer from Barnstead/Thermolyne Inc. (Dubuque, IA, USA). Oasis® HLB 6cc (200 mg/6 ml) was purchased from Waters Corporation (Milford, MA, USA). The digital refrigerator thermometer was purchased from Librati Trading Co. Ltd (Connaught Rd, Hong Kong). The vaporiser and nitrogen gas (N-Evap), were obtained from Organomation Associates Inc. (South Berlin, MA, USA) and the ultrasonic bath model 5510 from Branson (Danbury, CT, USA). The beaker (200 ml), round bottom flask (100 ml) and measuring cylinder (100 ml) were used to carry out the experiment.

Preparation of Stock Solution

Acetone (HPLC grade) was used to prepare the standard solution. The stock solution of diuron (100 µg ml⁻¹) was prepared by accurately weighing the exact amount of diuron and dissolving it in the correct volume of acetone. The solution was stored away from light, in a refrigerator. Working standard solutions used for obtaining the calibration curve were prepared by drying aliquots of the stock solution under a gentle nitrogen gas stream and redissolving the residues in an acetonitrile-water mixture (1:1, v/v) to the required concentration, prior to use.

HPLC-ultra Violet System

An Agilent 1100 HPLC system equipped with a quaternary pump (model G1311A), a degasser (model G1322A), an autosampler (model G1313A) and an ultra violet (UV) detector (model G1314A) were used for chromatography. The system was controlled by the Hewlett Packard ChemStation (Agilent Technologies), which also performed data collection from the UV detector and quantitative measurements. The UV detector was set at 254 nm for chromatographic determination. The column used was an Ascentis® RP-Amide column (25 cm x 4.6 mm, 5 µm) from Supelco (Bellefont, USA). The mobile phase consisted of acetonitrile (solvent A) and water-methanol (2.1, v/v) (solvent B). The ratio of solvent A to solvent B was 4:6 (v/v). The flow rate was 1.0 ml min⁻¹ and the volume injected was 100 µl. The column oven was set at 25°C and the analysing time was 15 min.

Experimental Details

The study was conducted at an oil palm plantation located near the Kuala Lumpur International Airport (KLIA) and Sepang International Circuit (SIC). The plantation is owned by the Malaysian Agriculture and Horticultural Association (MAHA). The number of palms planted per hectare was 160. The experimental site was located on flat land consisting of nine sub-
plots, measuring approximately 1.6 ha, with each plot containing 30 (5x6) palms. Eight-year-old palms ±7 m in height were used in the experiment. The plots were divided to two different dosage treatments which were the recommended and double the recommended dosage of diuron. Three sub-plots that were used as the control plots were only treated with 100% water. Each treatment plot was replicated thrice in a randomised block design.

The soil was analysed for its physico-chemical properties using standard laboratory methods (Allison, 1965; Day, 1965). The soil was sandy clay loam with the following physico-chemical properties: moisture (29.5%), total organic carbon (1.1%), clay (27.2%), silt (18.7%), sand (54.2%) and cation exchange capacity (CEC), (4.6 me/100 g). The pH of the soil was 5.4.

Diuron used in the treatments contained 80% a.i. It was sprayed with a conventional knapsack sprayer. The plot applied with diuron at the recommended rate was sprayed at 0.3 kg diuron ha⁻¹ while the plot with diuron applied at double the recommended dosage was sprayed at 0.6 kg diuron ha⁻¹. Diuron solution was sprayed at the rate of 450 litres ha⁻¹, around the base of the palms, radius 8 feet. The spraying started on 2 March 2010 (Day 0).

Soil Sampling

The soil samples for the spiking tests were sandy clay loam obtained from the oil palm plantation at KLIA, Sepang. The samples were taken from an area free of diuron application for at least three months. Soil samples were collected using an auger at the following depths: 0-10 cm, 10-20 cm, 20-30 cm, 30-40 cm and 40-50 cm. Three samples, taken from each depth were combined. The samples were taken at -1 (day before treatment), 0 (day of treatment, after 6 hr) 1, 3, 5, 7, 14, 21, 30, 60, 90 and 120 days after treatment (DAT). All the soil samples were air-dried at room temperature, for 20 min. The experiment was conducted in triplicate for samples spiked with diuron at 0.2, 0.6 and 1.0 µg g⁻¹. The extracts were then filtered with filter paper (Whatman, No. 4) at atmospheric pressure. A 10 ml extract was dried completely in nitrogen gas in a water bath set at 40°C. The residue was redissolved by adding 1 ml of a mixture of acetonitrile-water (1:1, v/v) using a vortex mixer and filtered through a 0.45 µm nylon filter to eliminate particulate material. The extract was then transferred to a 2 ml vial for further analysis.

Extraction of Diuron in Soil from Field Trial Plots

The 20 g soil samples from field trial plots were accurately weighed and placed in 250 ml conical flasks. Then, 5 g of sodium chloride and 40 ml of acetonitrile were added into the conical flask and transferred to the ultrasonic water bath maintained at room temperature, for 20 min. The experiment was conducted in triplicate for samples spiked with diuron at 0.2, 0.6 and 1.0 µg g⁻¹. The extracts were then filtered with filter paper (Whatman, No. 4) at atmospheric pressure. A 10 ml extract was dried completely in nitrogen gas in a water bath set at 40°C. The residue was redissolved by adding 1 ml of a mixture of acetonitrile-water (1:1, v/v) using a vortex mixer and filtered through a 0.45 µm nylon filter to eliminate particulate material. The extract was then transferred to a 2 ml vial for further analysis.

Determination of the Half-life of Diuron in Soil

The concentration of diuron residue obtained from different depths of the soil profile was used to plot the degradation of diuron. The graph logarithm concentration of diuron residue in the soil versus day of sampling was plotted. The half-life of diuron (t₁/₂) in the soil was calculated from the following equation:

$$ t_{1/2} = 0.693 / K, \text{ where } K \text{ is degradation coefficient rate.} $$

Weather Conditions

*Figure 1* shows the daily rainfall records at the KLIA Meteorological Station during the study period from 1 March until 4 July 2010. The highest monthly rainfall was recorded in March (208 mm) followed by April (172.5 mm), May (155 mm) and June (148.5 mm), respectively. The total rainfall from day 0 (day of treatment) to 120 DAT was 684 mm.
RESULTS AND DISCUSSION

Calibration Curve and Diuron Residue in the Soil Samples

The calibration curve for diuron was constructed using six points and based on the area measurement of working standards ranging from 0.05 to 1.0 µg ml⁻¹. A linear relationship between the peak area versus concentration was observed for diuron by using HPLC-UV analysis. The linear regression coefficient (r²) was found to be 0.9983 and the equation derived from the calibration curve was \( y = 626.82x + 16.28 \), where \( y \) is the area of the diuron peak obtained from the HPLC analysis and \( x \) is the concentration of diuron in µg ml⁻¹ (Figure 2). Since the linear regression obtained was 99.8%, the HPLC and detector were functioning efficiently (Tay, 2012; Fuad and Maher, 2010). It was also reported that the acceptance for linearity for the correlation coefficient is not less than 0.990.

<table>
<thead>
<tr>
<th>Concentration of diuron (µg g⁻¹) (n=3)</th>
<th>Recovery (%)</th>
<th>Relative standard deviation (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.2</td>
<td>95.0</td>
<td>2.6</td>
</tr>
<tr>
<td>0.6</td>
<td>93.2</td>
<td>1.5</td>
</tr>
<tr>
<td>1.0</td>
<td>94.1</td>
<td>4.8</td>
</tr>
</tbody>
</table>

Table 1. Percentage Recovery of Diuron from the Soil Samples

<table>
<thead>
<tr>
<th>Day</th>
<th>Depth (cm)</th>
<th>Concentration of diuron (µg g⁻¹), n=3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Day</td>
<td>Depth (cm)</td>
<td>Recommended dosage</td>
</tr>
<tr>
<td>-----</td>
<td>------------</td>
<td>---------------------</td>
</tr>
<tr>
<td>0</td>
<td>0 – 10</td>
<td>0.101 ± 0.013</td>
</tr>
<tr>
<td>10</td>
<td>20</td>
<td>0.027 ± 0.002</td>
</tr>
<tr>
<td>20</td>
<td>20 – 30</td>
<td>0.019 ± 0.002</td>
</tr>
<tr>
<td>30</td>
<td>40</td>
<td>0.014 ± 0.002</td>
</tr>
<tr>
<td>40</td>
<td>50</td>
<td>0.009 ± 0.001</td>
</tr>
</tbody>
</table>

Table 2. Concentration of Diuron (µg g⁻¹) in the Soil for the Two Dosages Applied

Figure 1. Daily rainfall records from March – June 2010 at Kuala Lumpur International Airport, Sepang.

Figure 2. Calibration curve of diuron using high pressure liquid chromatography-ultra violet.
TABLE 2. CONCENTRATION OF DIURON (µg g⁻¹) IN THE SOIL FOR THE TWO DOSAGES APPLIED (continued)

<table>
<thead>
<tr>
<th>Day</th>
<th>Depth (cm)</th>
<th>Concentration of diuron (µg g⁻¹), n=3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Recommended dosage</td>
</tr>
<tr>
<td>1</td>
<td>0-10</td>
<td>0.040 ± 0.002</td>
</tr>
<tr>
<td></td>
<td>10-20</td>
<td>0.014 ± 0.001</td>
</tr>
<tr>
<td></td>
<td>20-30</td>
<td>0.014 ± 0.001</td>
</tr>
<tr>
<td></td>
<td>30-40</td>
<td>0.018 ± 0.006</td>
</tr>
<tr>
<td></td>
<td>40-50</td>
<td>0.007 ± 0.001</td>
</tr>
<tr>
<td>3</td>
<td>0-10</td>
<td>0.041 ± 0.006</td>
</tr>
<tr>
<td></td>
<td>10-20</td>
<td>0.011 ± 0.001</td>
</tr>
<tr>
<td></td>
<td>20-30</td>
<td>0.008 ± 0.001</td>
</tr>
<tr>
<td></td>
<td>30-40</td>
<td>0.008 ± 0.001</td>
</tr>
<tr>
<td></td>
<td>40-50</td>
<td>0.007 ± 0.001</td>
</tr>
<tr>
<td>5</td>
<td>0-10</td>
<td>0.059 ± 0.002</td>
</tr>
<tr>
<td></td>
<td>10-20</td>
<td>0.012 ± 0.001</td>
</tr>
<tr>
<td></td>
<td>20-30</td>
<td>0.012 ± 0.003</td>
</tr>
<tr>
<td></td>
<td>30-40</td>
<td>0.009 ± 0.001</td>
</tr>
<tr>
<td></td>
<td>40-50</td>
<td>0.006 ± 0.001</td>
</tr>
<tr>
<td>7</td>
<td>0-10</td>
<td>0.079 ± 0.004</td>
</tr>
<tr>
<td></td>
<td>10-20</td>
<td>0.027 ± 0.001</td>
</tr>
<tr>
<td></td>
<td>20-30</td>
<td>0.024 ± 0.001</td>
</tr>
<tr>
<td></td>
<td>30-40</td>
<td>0.011 ± 0.001</td>
</tr>
<tr>
<td></td>
<td>40-50</td>
<td>0.017 ± 0.001</td>
</tr>
<tr>
<td>14</td>
<td>0-10</td>
<td>0.039 ± 0.002</td>
</tr>
<tr>
<td></td>
<td>10-20</td>
<td>0.008 ± 0.001</td>
</tr>
<tr>
<td></td>
<td>20-30</td>
<td>0.005 ± 0.001</td>
</tr>
<tr>
<td></td>
<td>30-40</td>
<td>0.008 ± 0.001</td>
</tr>
<tr>
<td></td>
<td>40-50</td>
<td>0.010 ± 0.004</td>
</tr>
<tr>
<td>21</td>
<td>0-10</td>
<td>0.033 ± 0.002</td>
</tr>
<tr>
<td></td>
<td>10-20</td>
<td>0.014 ± 0.001</td>
</tr>
<tr>
<td></td>
<td>20-30</td>
<td>0.003 ± 0.001</td>
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<tr>
<td></td>
<td>30-40</td>
<td>0.011 ± 0.002</td>
</tr>
<tr>
<td></td>
<td>40-50</td>
<td>0.013 ± 0.001</td>
</tr>
<tr>
<td>30</td>
<td>0-10</td>
<td>0.021 ± 0.003</td>
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<tr>
<td></td>
<td>10-20</td>
<td>0.007 ± 0.001</td>
</tr>
<tr>
<td></td>
<td>20-30</td>
<td>0.004 ± 0.001</td>
</tr>
<tr>
<td></td>
<td>30-40</td>
<td>0.002 ± 0.001</td>
</tr>
<tr>
<td></td>
<td>40-50</td>
<td>0.003 ± 0.001</td>
</tr>
<tr>
<td>60</td>
<td>0-10</td>
<td>0.013 ± 0.003</td>
</tr>
<tr>
<td></td>
<td>10-20</td>
<td>0.004 ± 0.001</td>
</tr>
<tr>
<td></td>
<td>20-30</td>
<td>0.003 ± 0.001</td>
</tr>
<tr>
<td></td>
<td>30-40</td>
<td>0.006 ± 0.001</td>
</tr>
<tr>
<td></td>
<td>40-50</td>
<td>0.004 ± 0.001</td>
</tr>
<tr>
<td>90</td>
<td>0-10</td>
<td>ND</td>
</tr>
<tr>
<td></td>
<td>10-20</td>
<td>ND</td>
</tr>
<tr>
<td></td>
<td>20-30</td>
<td>ND</td>
</tr>
<tr>
<td></td>
<td>30-40</td>
<td>ND</td>
</tr>
<tr>
<td></td>
<td>40-50</td>
<td>ND</td>
</tr>
<tr>
<td>120</td>
<td>0-10</td>
<td>ND</td>
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<td>10-20</td>
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<td></td>
<td>20-30</td>
<td>ND</td>
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<tr>
<td></td>
<td>30-40</td>
<td>ND</td>
</tr>
<tr>
<td></td>
<td>40-50</td>
<td>ND</td>
</tr>
</tbody>
</table>

Note: ND: not detected.

The highest concentration of diuron residue was detected on the day of treatment (Day 0) for both of dosages applied. As expected, it was found that the diuron residue detected for application at the recommended dosage plot was low when compared to that detected in plots applied at double the recommended dosage plot. The diuron residue was also detected at all depths (0-50 cm) up to 60 DAT for both the dosages. However, at 90 DAT the residue was detected at the 0-10 cm depth only when diuron was sprayed at double recommended dosage.

In the present study, the concentration of diuron residue detected was higher than values recorded in previous studies conducted by other researchers. Buszewski et al. (2006) reported that the concentration of diuron detected in the sandy soil studied was 0.018 µg g⁻¹. A mobility study of diuron conducted by Alva and Singh (1990) showed that diuron rapidly leached through the soil. The concentration of diuron residue was 0.08 µg g⁻¹ at the depth of 25 cm compared to 0.45 µg g⁻¹ at the depth of 120 cm. However, in the current study the results showed that the concentration of diuron decreased with increasing soil depth. This result is similar to that reported by Tworkoski et al. (2000), where the concentration of diuron was not
detected at the depth of 70 cm. This could be due to the similarity of physical characteristic of soil.

The factors that influence the persistence of diuron in the soil are the environment stability, water solubility (K_w), adsorption rate on the soil particles (soil organic-carbon adsorption coefficient, K_OC), pH, organic matter and rainfall (Kidd and James, 1991; Goody et al., 2002; Turner and Gillbanks, 2003; Muhamad et al., 2004; Ismail and Maznah, 2005; Halimah et al., 2010a). The K_OC values are useful to predict the mobility of organic soil contaminants. The higher K_OC values correspond to less mobile organic chemicals while lower K_OC values correspond to more mobile organic chemicals (USEPA, 2001). Diuron is stable in the environment with low water solubility (K_w = 42 mg litre⁻¹ at 25°C) and high adsorption rate on the soil particles (K_OC = 418 – 560) (Goody et al., 2002). In addition, diuron is not a volatile compound based on the low value of Henry’s constant which is 5.10 x 10⁻¹⁵ atm m³ mol⁻¹.

The persistence of diuron was reported to be directly proportional to the organic matter content of the soil (Alva and Singh, 1990; Adriana, 2004). The mobility of the diuron in the soil was highest when the percentage of organic matter was low. Another factor that favours the leaching process is high soil permeability to water, especially in coarse soils. The organic matter content of the soil in the study area was low (3.8%). Therefore, the mobility of the diuron residue in this study was higher due to the higher content of organic matter. The diuron residue was detected at the depth of 50 cm on the day of treatment (Day 0) and up to 60 DAT. A similar result was reported by Janitha et al. (2006), who indicated that low diuron residue was detected in 43 types of soil such as Agalawatta, Akurana, Boralu etc. with low organic matter content in Sri Lanka.

In addition, the pH of the soil also affects the persistence of diuron in soil. According to Hager and Refsell (2008), the higher soil pH can decreased the adsorption of herbicides in soils. Chemical breakdown and microbial breakdown are often slower in soils of higher pH. In the present study, the pH of the soil in the study area was low (pH 5.4). Hence, the adsorption of diuron slightly increased and therefore diuron persisted when applied at both dosages.

Soil moisture also affects the persistence and rate of degradation of pesticides in the soil. According to Ismail and Maznah (2005), the rate of pesticide degradation increased with increasing soil moisture. Water molecules in the soil compete with pesticides for adsorption onto the colloids in the soil. This phenomenon will cause an increase in the concentration of pesticides in the soil. In the current study, the detectable residue of diuron was high and persistent because of the low soil moisture content which was 29.5%.

The persistence and adsorption of pesticides in the soil are also dependent on the soil grain size, for the CEC value. The CEC values are directly proportional to the persistence and adsorption onto the soil, but inversely proportional to the pesticides leaching into the soil (Maznah, 2005). However, in the present study, the results showed that the low CEC values at 4.63 g me/100 g caused increased persistence of diuron in the soil. This study also showed that diuron leached fast and was detected at a depth of 50 cm on the day of spraying (Day 0).

Rainfall also affects the persistence and mobility of diuron in the environment. Diuron residue on the soil surface can flow into reservoirs, lakes and rivers and can also be leached underground (Vououlis et al., 2002; Guardia-Rubio et al., 2006; Lourencetti et al., 2008). In the current study, the highest rainfall was recorded from March until June. On the day of treatment (Day 0, 2 March 2010), 15 mm of rainfall was recorded in the morning, and 3 mm in the evening. This shows that the treatment was carried out during the rainy season. That could be the reason why diuron residue was detected at the depth of 0-50 cm 6 hr after application.

The biotic and abiotic factors such as hydrolysis, photolysis and microbial activity in the soil could enhance the degradation rate of pesticides especially under the Malaysian climatic conditions (Ismail et al., 2004). Volatilisation, runoff and leaching processes could affect the degradation rate as well. Microbial degradation is the primary means of diuron dissipation in the soil, while photodegradation is not considered a primary dissipation route (Hess and Warren, 2002). Due to the persistence and mobility of diuron, its half-life in each segment of the soil profile was calculated as mentioned earlier. Table 3 shows that the half-life of diuron in the field plots for application rates at the recommended and double the recommended dosage ranging from 22.35-49.5 days and 18.73-57.75 days, respectively. The half-life of diuron in each segment of the soil for plots sprayed at the recommended dosage was 24.8 days (0-10 cm), 27.7 days (10-20 cm), 22.4 days (20-30 cm), 38.5 days (30-40 cm) and 49.5 days (40-50 cm), respectively. Meanwhile, for plots sprayed at double the recommended dosage the half-lives were 18.7 days (0-10 cm), 31.5 days (10-20 cm), 46.2 days (20-30 cm), 57.8 days (30-40 cm) and 21.7 days (40-50 cm).

Most studies on the persistence of diuron residues in soil reported that the half-life of diuron ranged from 90 – 365 days, depending on the application rate and various other factors mentioned, such as environment stability, water solubility, adsorption rate on the soil particles, pH, organic matter and rainfall (Kidd and James, 1991; Adriana, 2004; Anon., 2005). Adriana (2004) reported that the half-life of diuron in plots treated...
with diuron for 12 years, was 37 days. Our results differed because the current study was conducted under tropical conditions where there are considerable differences from temperate conditions such as soil pH, type of soil and seasons (summer, spring, winter and autumn). According to Ismail et al. (2004), the degradation rates of pesticides in tropical soils are much faster than those under temperate conditions.

**Half-life for Diuron in Soil**

Half-life of diuron in the soil was determined by drawing a graph of ln diuron concentration versus sampling day. The graph was plotted using diuron concentration at soil depths of 0-10, 10-20, 20-30, 30-40 and 40-50 cm for the trial plots treated with the recommended and double recommended dosage. Figure 3 shows the graph logarithm concentrations of diuron residue in the soil versus day of sampling at the recommended dosage. Meanwhile, Figure 4 is the graph logarithm concentrations of diuron residue in the soil versus day of sampling at the double recommended dosage. The results showed that the half-life of diuron in the soil for both dosages vary according to the depth of soil profile. This study has found concordance with the results of other studies (Beigel et al., 1999; Fomsguard, 1994; Plimmer, 1992) where the reaction of pesticides in the environment is complex because they are affected by various factors such as pesticide chemical structures, reactions of microbes, water and oxygen content in soil, initial concentration and spray method and the type of soil pesticides. Van der Werf (1996) also suggested the loss of pesticides after spraying through decomposition process, sprays where pesticides evaporated into the air, leaching into the soil and being absorbed by soil microorganisms or adsorbed on soil particles.

The recommended dosage for the half-life of diuron at 40-50 cm depth was 49.5 days which is the longest half-life recorded in this study, when compared with the other soil depth profile (Table 3). Meanwhile, the shortest half-life of diuron was at a depth of 20-30 cm of the soil profile at 22.4 days

<table>
<thead>
<tr>
<th>Depth of soil (cm)</th>
<th>y = mx+c</th>
<th>r²</th>
<th>K (degradation coefficient rate)</th>
<th>t½</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recommended dosage</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-10</td>
<td>y = -0.028x - 2.7734</td>
<td>0.750</td>
<td>0.028</td>
<td>24.75</td>
</tr>
<tr>
<td>10-20</td>
<td>y = -0.025x - 4.0507</td>
<td>0.630</td>
<td>0.025</td>
<td>27.72</td>
</tr>
<tr>
<td>20-30</td>
<td>y = -0.031x - 4.3639</td>
<td>0.574</td>
<td>0.031</td>
<td>22.35</td>
</tr>
<tr>
<td>30-40</td>
<td>y = -0.018x - 4.4890</td>
<td>0.323</td>
<td>0.018</td>
<td>38.50</td>
</tr>
<tr>
<td>40-50</td>
<td>y = -0.014x - 4.6703</td>
<td>0.272</td>
<td>0.014</td>
<td>49.05</td>
</tr>
<tr>
<td>Double the recommended dosage</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-10</td>
<td>y = -0.037x - 1.7918</td>
<td>0.889</td>
<td>0.037</td>
<td>18.73</td>
</tr>
<tr>
<td>10-20</td>
<td>y = -0.022x - 3.5418</td>
<td>0.512</td>
<td>0.022</td>
<td>31.50</td>
</tr>
<tr>
<td>20-30</td>
<td>y = -0.015x - 4.1858</td>
<td>0.171</td>
<td>0.015</td>
<td>46.20</td>
</tr>
<tr>
<td>30-40</td>
<td>y = -0.012x - 4.5819</td>
<td>0.120</td>
<td>0.012</td>
<td>57.75</td>
</tr>
<tr>
<td>40-50</td>
<td>y = -0.032x - 5.0413</td>
<td>0.438</td>
<td>0.032</td>
<td>21.66</td>
</tr>
</tbody>
</table>

**Figure 3.** The graph logarithm concentrations of diuron residue in the soil vs. day of sampling at recommended dosage.
(Table 3). From this study, the loss of diuron was also due to a number of factors: evaporation in the air during spraying, leaching of diuron in the soil, degradation by microorganism and the intensity of rainfall.

CONCLUSION

Diuron is moderately to highly persistent in the soil and this is influenced by the physico-chemical properties of the soil environment stability, water solubility and adsorption rate onto the soil particles. In the present study, diuron was highly persistent in the sandy clay loam soil at the two dosages applied. Diuron residue was detected at 60 DAT when applied at the recommended dosage, while for application at double the recommended dosage diuron was detected up to 90 DAT at 0-10 cm depth. Therefore, it is not surprising that diuron was detected on the soil surface on Day 90. Diuron residues were detected at 0-50 cm depth from 0 until 60 DAT. The half-life was calculated and found to be in the range of 22.35 – 49.5 days (recommended dosage) and 18.73 – 57.75 days (double the recommended dosage). The calculated half-life of diuron in the present study was shorter compared to those obtained in other studies and this is attributed to low organic matter content.

ACKNOWLEDGEMENT

The authors would like to thank MPOB for financially supporting this work and the Director-General of MPOB for permission to publish this article. Appreciation is expressed to the Malaysian Agriculture and Horticulture Sdn Bhd and its staff for their help in completing field research. The authors are also indebted Ms Rosilawati and Ms Rosliza for the technical support.

REFERENCES


THE FATE OF DIURON IN SOIL IN A MALAYSIAN OIL PALM PLANTATION


