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Mobility and Persistence of Metolachlor in Two Common Malaysian Agricultural Soils

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The acetanilide herbicides such as metolachlor are soil-active herbicides. In Malaysia, metolachlor is used to control weeds in corn (*Zea mays* L.), peanut (*Arachis hypogaea* L.), sugarcane (*Saccharum* sp.), and cassava (*Manihot esculenta* L.).

Since the herbicide is directly applied to the soil, its performance is highly dependent on soil characteristics (Ashton and Monaco 1991). The primary factors affecting soil degradation of acetanilide herbicides are adsorption while microbial degradation is the most important factor in determining their overall fate in the environment (Stamper and Tuovinen 1998). It has been reported that metolachlor was readily leached in the soil column with 34% of metolachlor found in the leachate (Kim and Feagley 1998). There have been several reports on the degradation of metolachlor and alachlor in temperate regions (Zimdahl and Clark 1982; Peter and Weber 1985), however, information pertaining to the influence of soil properties on degradation of these herbicides is still limited, especially under tropical conditions. Generally the degradation rate decreases and adsorption increases with increasing soil organic matter and clay content. Ninety percent of all acetanilide loss is due to microbial degradation (WSSA 1989). As acetanilide herbicides are degraded rapidly by microbes, the soil half-life is relatively short. Kontchou and Gschwind (1998) suggested that variations in the rates of herbicide degradation in different soil types at different temperatures and soil moisture levels arise from the variations in microbial activity and herbicide availability in the soil solution. For instance, Gaynor et al. (1998) reported that the half-life of metolachlor decreased during the dry season when the soil moisture content was low. The half-life of metolachlor has been estimated as 30 to 50 days in the northern areas and 15 to 25 days in the southern areas of the United States (WSSA 1989), and between 31 to 66 days in Ontario soil, in Canada (Gaynor et al. 1998). More information on the behaviour and fate of metolachlor in different soil types under tropical conditions is needed in order to avoid adverse effects on subsequent crops and soil fertility.

The aim of the present study was to examine the persistence and mobility of metolachlor, in two common agricultural soils in Malaysia, namely the Sungai

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Table 1. Physico-chemical properties of the Sungai Buluh and Holyrood series soils

Soil characteristics	Sungai Buloh series	Holyrood series
Organic carbon (%)	2.0	1.0
Clay (%)	10.0	21.1
Silt (%)	3.7	4.1
Sand (%)	86.3	74.8
pH (distilled water)	4.8	4.6
Total nitrogen (%)	0.14	0.12
CEC* (meq/100g)	4.6	4.8
WHC* (%w/w)	27.4	25.3
Soil texture	Loamy sand	Sandy loam

*CEC: cationic exchange capacity; WHC: water holding capacity

Buluh series and the Holyrood series. We chose these soils because of their different soil texture, the Sungai Buluh series containing a higher amount of organic matter than the Holyrood series.

MATERIALS AND METHODS

The two soil series used in this study were the Sungai Buluh series and the Holyrood series. The experiments were conducted at the Rubber Research Institute of Malaysia (RRIM), Sungai Buluh, Selangor. The physico-chemical properties of the soils are shown in Table 1. The herbicide used in the study was emulsifiable concentrate formulations of metolachlor (Dual®). Cucumber plants were used as the bioassay species because they have a marked sensitivity to acetanilide herbicides and are easy to grow.

Plots measuring (5 m x 4 m) each with 0.5 m between adjacent plots were prepared in the RRIM experimental area. The plots were simultaneously prepared and hand-weeded until the experiment commenced. The plots were sprayed with metolachlor at 1.04 kg a.i./ha using a knapsack sprayer with a volume equivalent to 450 L/ha at 200 kPa. The untreated control plot was sprayed with water. The experiments were carried out from September 1995 until December 1995.

Composite samples of 8 soil cores 0-6.5, 6.5 – 13, 13-19.5 and 19.5-26 cm deep from each plot with the herbicide were taken at random on days 0 (immediately after spraying), 14, 21, 49 and 84 days after spraying. Sampling was continued until bioassay analyses showed no effect of the herbicide on bioassay species. Samples were placed in plastic-lined bags and bioassayed. For the bioassay, soil samples of each depth from each replicate were air-dried overnight and mixed thoroughly. Approximately 200 g of soil from each composite sample was placed in a 12-cm plastic pot in which 10 bioassay seeds were planted at depth of 0.5 cm. Soil samples were bioassayed in the greenhouse under natural light. The greenhouse temperature averaged 32±2°C, and soil moisture content was maintained at approximately 90% field capacity. After emergence, bioassay plants were thinned to 6 seedlings per pot. Eight days after emergence, the plants were harvested by cutting at soil level. The fresh weight of the seedlings was recorded and expressed as a percentage of the control value. The concentration of the herbicide residue in the soil was then determined using the dose-response curve, which was run concurrently.

The experimental design used was a completely randomized block design with four replications. Data was subjected to analysis of variance, and the means were compared with the least significant difference (LSD) test at a 5% level of probability. The dissipation rate constant was calculated by linear regression from the transformed first-order rate equation, $ln\ C_0/C_i = K_t$, where C_0 is the concentration (ppm) determined after incubation, C_i the initial concentration (ppm), K the rate constant (day^{-1}), and t the time (day). The time when 50% of the herbicide had dissipated (DT_{50}) was calculated from the equation $DT_{50} = 0.693/K$.

A standard curve for each soil series was plotted using the cucumber plant for bioassay in order to define linearly the concentration range of metolachlor in the soils used for the greenhouse studies. Concentrations used for the herbicide in each soil type were 0, 0.1, 0.2, 0.3, 0.5, 1.0, 2.0, 3.0, 4.0 and 6.0 ppm (w/w). The required volume of the herbicide was thoroughly mixed with the air-dried soil to obtain the final concentration. The soil samples were bioassayed in the greenhouse under natural light. Treated soil (2.0 kg) of each concentration of the herbicide was transferred into pots, each containing 400 g of soil, in which five cucumber seeds were planted at a depth of 1 cm. The soil moisture was maintained at about 70-100% of field capacity. After emergence the seedlings were thinned to two per pot. Eight days after emergence, the plants were harvested by cutting at soil level and fresh weight was recorded. The fresh weight of five replicates (expressed as a percentage of the control value) was plotted against the log of the herbicide concentration (Zimdahl and Clark 1982). The amount of herbicide required to produce a 50% growth reduction (GR_{50}) compared with the control was determined from each response curve. The GR_{50} values, expressed as ppm (parts per million by weight of herbicide in the oven-dry soil), were used in the correlation work presented.

RESULTS AND DISCUSSION

Degradation of metolachlor in the soil under laboratory conditions fit first-order kinetics. The average r^2 of log-transformed first-order equation for the two soils studied was 0.96 (Sungai Buluh series) and 0.99 (Holyrood series). The concentration of herbicides required to cause a 50% reduction in the fresh weight (GR_{50}) of the cucumber plant varied, depending on the soil type used. The results

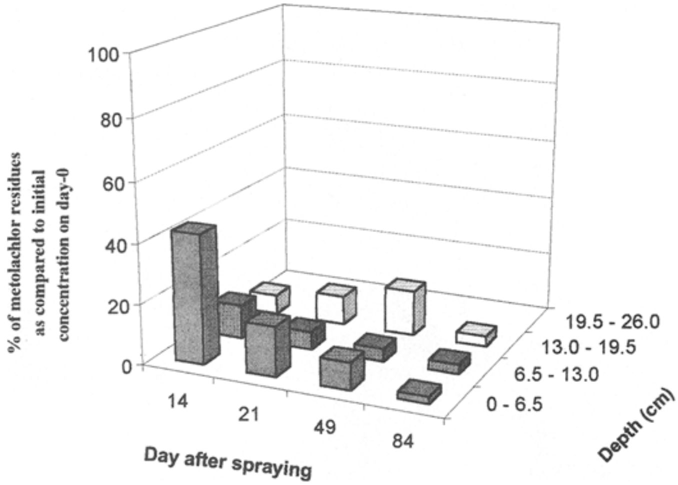

Figure 1. Percentage of metolachlor in the Sungai Buluh series soil of different depths over time

Table 2. First-order degradation rate constants (K), GR_{50} and half life (DT_{50}) of metolachlor in soils

Soil type	GR_{50}(ppm)	K day^{-1}	r^2	DT_{50} day
Sungai Buluh	22.24	0.048± 0.0185	0.96	14±4.0
Holyrood	9.31	0.094±0.0548	0.99	7±2.0

±95% of confidence limit

showed that the amount of the herbicides required for GR_{50} was higher in the Sungai Buluh series than in the Holyrood series (Table 2). The amounts of metolachlor residues in the two soils were reduced with increasing incubation period.

Fourteen days after application and exposure to 67.9 mm total rain with an average of 4.85 mm/day under natural conditions, the herbicide was located in the 13 – 19.5 cm layer of the profile of the Sungai Buluh series soil (Fig. 1). About 40% (of the initial application) of metolachlor residue accumulated in the 0-6.5 cm zone but decreased with depth. After 84 days with a total 152.8 mm rainfall, a significant amount of metolachlor (3.42% of the initial application) was observed in 13-19.5 cm depth. No residue was detected in soil zones deeper than 19.5 cm.

From fourteen and 21 days after application, a significant amount of metolachlor residue was detected in the 19.5 – 26.0 cm depth in Holyrood series soil (Fig. 2).

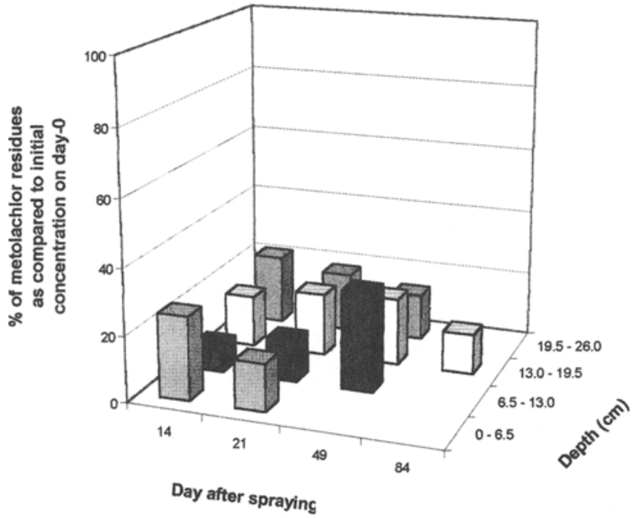

Figure 2. Percentage of metolachlor in the Holyrood series soil at different depths over time

As the time of exposure was prolonged to 49 days, metolachlor continued to move downward and no residual effect was detected in the upper zone. On day-84 after application, significant amounts of the herbicide residue were detected only in the 13-19.5 cm depth.

The persistence of a herbicide in soils is greatly influenced by its physical properties, physico-chemical characteristics, microbial activity and diversity of the soil. The persistence of a herbicide has an inverse positive relationship with its adsorption characteristic onto soil particles. Regression analysis showed that organic matter content was highly related to GR_{50} of the metolachlor with r values of 0.96 and 0.99 for Sungai Buluh and Holyrood series, respectively. Several researchers have reported that the adsorption of most herbicides was positively correlated with organic carbon (Braverman et al. 1986; Mueller and Banks 1991). Herbicide adsorption to soil particles is negatively correlated with the persistence of the particular herbicide in soil (Ismail and Hanijah 1999).

Metolachlor adsorption was shown to be positively correlated with organic matter content (r=0.79). This observation is in line with Braverman et al. (1986) who found that phytotoxicity of metolachlor on *Oryza sativa* was lower in soil with high organic matter due to higher adsorption. Our results clearly showed that less metolachlor was needed for GR_{50} of the plant's fresh weight in the Holyrood series soil which contained lower organic matter than Sungai Buluh series soil. The lower GR_{50} value of metolachlor for Holyrood series soil is best explained by assuming that the compound could be easily taken up by the bioassay species in soil moisture of 70 to 100% of field capacity. At higher moisture levels, the residue could also be released into the soil solution and be taken up by the bioassay species.

The results of these experiments therefore showed marked differences in the persistency of an acetanilide herbicide in two soils of different texture and properties. Metolachlor persisted longer in Sungai Buluh series soil with high content of organic matter as compared to the Holyrood series. This result correlated with the report of Peter and Weber (1985). It appears that organic matter content of soils plays an important role in determining GR_{50} fresh weight of bioassay species.

It is also noteworthy that more metolachlor residues could be detected in 19.5 – 26 cm depth in the Holyrood but not in the Sungai Buluh series soil, showing that metolachlor moved downward slightly more in the Holyrood than the Sungai Buluh series and this could be explained by the adsorption process.

These results are in general agreement with other published data (Stamper and Tuovinen 1998), which demonstrated that metolachlor has an affinity for organic matter and that under condition of high rainfall, the herbicide will leach from the topsoil into deeper soil layers, especially in soils with less organic matter. The amount of water or the frequency of rain directly increased the extent of leaching of metolachlor. With high rainfall in tropical areas, this herbicide could move downward and contaminate groundwater. However, there is no report on the persistence of metolachlor in water under tropical conditions.

The above experiments showed the following: a) adsorption and bioactivity of the metolachlor were directly correlated to organic matter content; b) the herbicide persisted longer in soils with higher organic matter; c) metolachlor moved downward faster in soils with less organic matter. The results indicate very clearly the fate of metolachlor under field conditions in tropical environments.

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