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Pattern and Rate of Dissipation of Pretilachlor and Mefenacet in Plow Layer and Paddy Water under Lowland Field Conditions: A Three-year Study

Ferdinand F. Fajardo, Kazuhiro Takagi,[†,*] Masumi Ishizaka[†] and Kenji Usui

Institute of Applied Biochemistry, University of Tsukuba, Tennodai 1-1-1, Tsukuba, Ibaraki 305-8572, Japan
[†] Herbicide Chemistry Laboratory, National Institute of Agro-Environmental Sciences, Kanondai 3-1-1, Tsukuba, Ibaraki 305-8604, Japan

Field trials were conducted at the National Institute of Agro-Environmental Sciences experiment station from 1995 to 1997. Each trial was carried out from mid-May to early July every year. Determining the pattern and rate of dissipation of pretilachlor and mefenacet in paddy soil at three different depths (0–1, 1–5 and 5–10 cm) and in paddy water was the primary objective of the experiments. Half-lives (DT_{50}) of the herbicides were calculated using both the simple first order kinetics (SFOK) and the biphasic first order kinetics (BFOK). The pattern and rate of dissipation of pretilachlor in both soil and water were quite different from that of mefenacet. At the 0–1 cm soil layer (oxidative), dissipation of pretilachlor was quite rapid during the first 3 weeks but slowed down afterwards. In case of mefenacet, dissipation was a steady decline until the last sampling day. The DT_{50} in this layer was between 9 to 11 days and 7 to 10 days for mefenacet and pretilachlor, respectively. At the lower soil layers (1–5 and 5–10 cm; reductive) pretilachlor appeared to leach from the upper layer within the first two weeks and then quickly disappeared afterwards. Faster degradation of pretilachlor was noted in these reductive soil layers. On the other hand, mefenacet dissipation declined steadily at these layers. Also, leaching of mefenacet was not as evident as in pretilachlor. Mefenacet concentration in paddy water peaked over the second to third day and its dissipation was rapid until the fourth week. Dissipation pattern of pretilachlor was a steady curvilinear decline. In paddy water, DT_{50} was about 3.3 to 4.1 days for mefenacet and 3.0 to 3.6 days for pretilachlor. Calculating the half-life in soil (0–1 cm layer) using SFOK appears sufficient for mefenacet while a more complex model such as the BFOK describes that of pretilachlor better. The half-life and dissipation pattern of both herbicides did not vary considerably across years. There was no evidence of residue build-up due to continuous application of the herbicides in the same plots.

Key words: dissipation, half-life, pretilachlor, mefenacet, first-order kinetics, 3 soil layers.

INTRODUCTION

Mefenacet and pretilachlor are two of the most popular herbicides for lowland rice in Japan and other parts of Asia. Mefenacet [2-(1,3-benzothiazol-2-yloxy)-*N*-methylacetanilide] was developed for the pre-emergence control of graminaceous and some dicot weeds in rice[1–3] while pretilachlor (2-chloro-2′,6′-diethyl-*N*-(2-propoxyethyl)acetanilide) was developed for the selective control of some annual weeds in lowland rice including barnyardgrass.[4–6]

Many studies were conducted, especially in Europe and America, regarding herbicide behavior in upland conditions but very few dealt with lowland conditions. In Japan, a very limited number of researches have been made in this area.[7,8]

Currently, great emphasis is being put to the environmental fate of agricultural pesticides. Herbicides, being important agricultural chemicals, are surely one of the targets for environmental concern. To be more effective, a herbicide needs to kill more weed species and stay in the soil for a longer period of time.[9] Rahman and James[10] also said that a soil acting herbicide must be able to maintain an effective concentration when weed control is necessary for proper crop growth. They, however, pointed out that it should not persist excessively as it may pose a threat to the succeeding crop as well as to the environment. Hence, a longer dissipation period of a

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* To whom correspondence should be addressed.

herbicide may raise problems for its environmental safety. It is, therefore, appropriate to conduct studies on the dissipation of herbicides in the plow layer and in water and relate it to its environmental soundness. Thus, it was the aim of this study to determine the pattern and rate of dissipation of mefenacet and pretilachlor under actual lowland conditions and to see whether the continuous application of these herbicides would cause a residue buildup in the soil.

MATERIALS AND METHODS

1. Field Experimental Design and Management Practices

All experiments were conducted at the field experiment station of the National Institute of Agro-Environmental Sciences (NIAES) in Kanondai, Tsukuba, Ibaraki from May–July of 1995, 1996 and 1997. The soil in the experimental field was light clay classified as alluvial (46.7% sand; 19.4% silt; 33.9% clay; MWHC=57.5%; pH (in water)=5.2; 1.83% organic carbon; total N=0.15%; CEC=122 mmol/kg).

During each experimental period, the plots (9 m×9 m) were planted to rice (*Oryza sativa* L. cv. Nipponbare) at 40 cm×30 cm spacing. Commercial granular formulations (each at 4 kg/10 a) were used in the experiment with Hayate® (1.5% pretilachlor, 5% dymrone, 0.3% imazosulfuron; 0.2% dimethametryn) as the source of pretilachlor and Zark-D® (3.5% mefenacet, 1.5% dymrone, 0.17% bensulfuron methyl) as the source of mefenacet. Herbicides were applied between 5 and 6 days after transplanting by manual broadcasting.

2. Sampling and Preparation
2.1 Soil

At each sampling time, 5 random spots were used for taking soil samples. Sampling times were at (or around) 0, 1, 3, 7, 14, 21, 28, 35, 42, 49 and 52 days after herbicide application (DAHA). Sampling depths were 0–1, 1–5 and 5–10 cm. The 0–1 cm samples were taken by scraping the topsoil using a stainless steel spatula marked to the 1 cm level. At the same spot, for lower soil layers (1–5 and 5–10 cm), a stainless steel core sampler (35 mm diameter×150 mm depth) was used. Right after sampling soil samples were bulked according to depth and mixed thoroughly in a stainless steel bowl. They were then placed in glass jars, properly labeled and were kept in the freezer at −20°C until ready for extraction and analysis.

2.2 Paddy water

Water sampling was made at (or around) 0, 1, 3, 7, 9, 14, 21, 28, 35, 42 and 49 DAHA. Samples were taken from several random spots in each plot. From each plot, a 500 ml sample was collected during the first 2 weeks and was gradually increased by 500 ml increment from the third week onwards.

Both soil and water samples were analyzed for herbicide residues using gas chromatography (GC) the details of which are presented in the succeeding sections. The method used for the residue analysis was developed at the Herbicide Chemistry Laboratory of NIAES.

3. Herbicide Extraction and Clean-up Procedures
3.1 In soil

Soil samples (20 g fresh weight, 2 replicates per sample) were put into a 200 ml Erlenmeyer flask together with 100 ml acetone. Samples were then sonicated for about 3 minutes, shaken for 30 minutes then filtered using a 60 ϕm/m filter paper (Kiriyama no. 5A) and the filtrate collected in a 200 ml round bottom flask. The remaining soil in the Erlenmeyer flask was washed with 50 ml acetone; the washing filtered and the filtrate added into the sample in the round bottom flask. The filtrate was concentrated in a rotary evaporator at 40–45°C until the acetone was removed or until the residue was about 10 ml. The residue was then poured into a 200 ml separatory funnel containing 30 ml of 5% NaCl solution. The round bottom flask was washed with 30 ml hexane and the washings poured into the separatory funnel and then shaken vigorously for about 2 minutes. The water layer was saved while the hexane layer was filtered using a Silicone treated filter paper (Whatman 1PS) and the filtrate was collected in a 100 ml Kjeldahl flask. The saved water layer was again extracted repeating the above procedure *i.e.*, from shaking to filtration. The combined extracts were then evaporated to dryness at 40–45°C in a rotary evaporator or in an automated evaporator (Zymark TurboVap II) at 50°C for 25 minutes.

Re-extraction was made using either 10 ml hexane or 10 ml acetone. Aliquots of samples were analyzed using GC. Pretilachlor had a 89.8% recovery (S.D.=3.0; n=3) while mefenacet had 96.9% (S.D.=3.0; n=3).

3.2 In water

Water samples were filtered using a glass fiber filter paper (Whatman GF/B). Sep-Pak C18 cartridges (2 per sample) were pre-conditioned by washing with 5 ml acetone, 5 ml methanol (grade 300) and 8 ml distilled water. Filtered water (1–2 week samples with pH adjusted to about 6.5–7.0) were passed through the conditioned cartridges in a Waters concentrator pump for 20 minutes at a flow rate of 10ml/min. For the 3–4 week samples, flow rate was 10ml/min for 60 minutes and 10ml/min for 100 minutes for the 5th to 7th week samples. "Concentrated" cartridges were then dried over a Waters vacuum manifold for about 30 minutes then eluted with 5 ml acetone (grade 300). The eluate was collected in a 10 ml graduated glass tube, covered tightly and stored in the refrigerator until ready for analysis. Before GC analysis, samples were dried up and redissolved with appropriate amounts of acetone (grade 300).

The recovery for pretilachlor was 93.8% (S.D.=3.4; n=3) and 91.7% (S.D.=3.8; n=3) for mefenacet.

4. Gas Chromatographic Analysis

A Hewlett Packard HP 5890 Series II gas chromatograph with nitrogen-phosphorous detector (NPD) was used for the analysis. The column was a HP-50+ with 50% Ph Me Silicone gum. It was a split less capillary type with an inside diameter of 0.53 mm, a length of 15 m and a film thickness of 1 μm. Temperature settings for pretilachlor were 200°C for oven, 250°C for injector port and 280°C for detector. For mefenacet, temperature settings were 250°C, 280°C and 280°C for oven, injector port and detector, respectively. The machine was equipped with an automatic sampler with the injection volume set to 2 μl.

5. Data analysis

Dissipation rate was calculated using both the simple first order kinetics (SFOK) or the biphasic first order kinetics (BFOK).[11] The equation $C = C_0 e^{-kt}$ was used for the 1st order kinetics where C is the amount of herbicide (mg kg^{-1} soil or mg l^{-1} water) at time t; C_0 is the amount of herbicide (mg kg^{-1} soil or mg l^{-1} water) at time 0; k is the rate constant (day^{-1}) and t is time (day). The dissipation rate constant (k) was calculated by linear regression from the transformed first-order rate equation, $\ln C = \ln C_0 - kt$. Half-life (DT$_{50}$) was calculated using the equation $-\ln(0.5)/k$.

RESULTS

1. Pretilachlor

The dissipation pattern of pretilachlor in 0–1 cm soil and in paddy water is presented in Fig. 1. The pattern is quite similar across years. In soil, dissipation was quick during the first 3 weeks then slowed down from the third week onwards. For the 0–1 cm layer, R^2 values

using the SFOK was generally lower than the BFOK. In water, R^2 values were acceptable when the SFOK was used, thus, it appeared to be sufficient for calculating the half-life. The half-life in soil was generally shorter in 1996 compared to 1995 and 1997 while it was generally
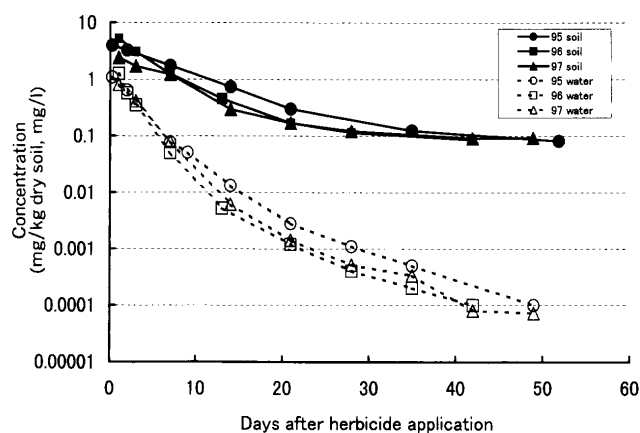

Fig. 1 Pretilachlor dissipation in 0–1 cm layer paddy soil and in paddy water. NIAES Experiment Station, 1995–1997.
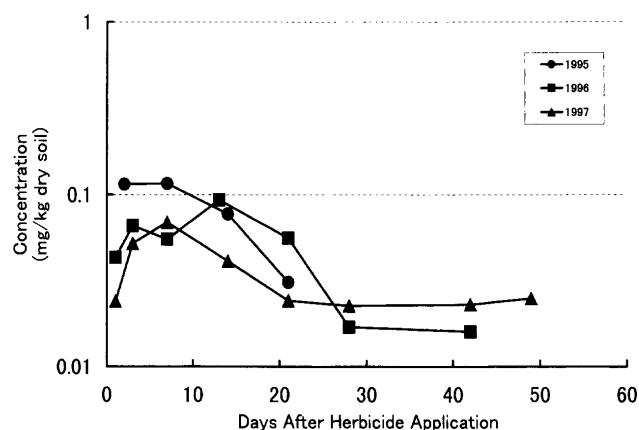

Fig. 2 Pretilachlor dissipation in 1–5 cm layer in a paddy field. NIAES Experiment Station, 1995–1997.

Table 1 Half life (DT$_{50}$), dissipation rate (k) and R^2 values for pretilachlor in 0–1 cm soil layer and in paddy water, NIAES field station.

| Year | Simple first order kinetics 1 to 52 | | | Biphasic first order kinetics | | | | | |
| | | | | 1 to 21 | | | 21 up | | |
	k	R^2	DT$_{50}$	k	R^2	DT$_{50}$	k	R^2	DT$_{50}$
0–1 cm soil									
1995	0.0789	0.9269	8.8	0.1242	0.9998	5.6	0.0415	0.9335	16.7
1996	0.1025	0.8684	6.8	0.1699	0.9794	4.1	0.0310	0.9267	22.4
1997	0.0698	0.8357	9.9	0.1384	0.9760	5.0	0.0287	0.9502	24.2
Paddy water									
1995	0.1901	0.9400	3.6	0.2907	0.9799	2.4	0.1180	0.9989	5.9
1996	0.2293	0.9254	3.0	0.3492	0.9605	2.0	0.1164	0.9854	6.0
1997	0.1969	0.9264	3.5	0.3262	0.9850	2.1	0.1117	0.9505	6.2

Biphasic 1st order=two regression lines are used to describe the degradation of the herbicide, i.e., one for the 1st 3 weeks and another for the 3rd week onwards. DT$_{50}$=half life (in days); computed using the equation $-\ln(0.5)/k$. k=dissipation rate; slope of the regression line.
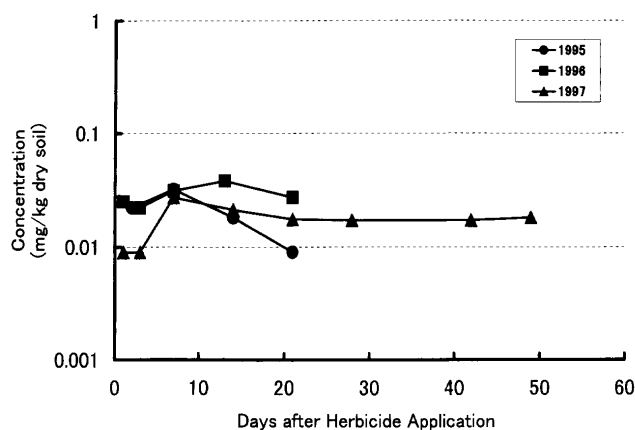
Fig. 3 Pretilachlor dissipation in 5–10 cm layer in a paddy field. NIAES Experiment Station, 1995–1997.

similar in water (Table 1). The half-life (using SFOK) ranged from about 6.8 to 9.9 days and 3.0 to 3.6 days in the 0–1 cm layer and water, respectively.

Figs. 2 and 3 show the dissipation pattern at the 1–5 and 5–10 cm soil layers. In 1995, the first year when pretilachlor was applied, in both soil layers, residues were not detected after 21 DAHA. The same was true in 1996 at the 5–10 cm soil layer. Residues were beyond the non-detectable level (in soil) which was below 0.005 mg kg^{-1} dry soil. In 1997, however, residues were detected until about 50 days in both layers. In 1995 and 1997, pretilachlor concentration abruptly increased at 7 DAHA then decreased again until 21 DAHA while in 1996, the increase was evident until 14 DAHA. In all years, dissipation appeared to be almost stagnant from 21 DAHA. The amount of residue remained at almost the same level in all years.

2. Mefenacet

The typical dissipation pattern of mefenacet in 0–1 cm soil and in paddy water is presented in Fig. 4. The pattern appears to be uniform across years. Dissipation at the 0–1 cm soil layer is gradual and fits a straight downward slope while in water it appeared to be fast during the first 4 weeks and gradually slowed down from then on. Table 2 shows the half-life, degradation rate and R^2 values in 0–1 cm soil and in paddy water from 1995 to 1997. For both soil and water, the SFOK appears to be sufficient in calculating for the half-life as reflected in the high R^2 values. Although the dissipation pattern of water appeared to be biphasic, the R^2 values for the 2nd phase (over 21 days) are generally lower indicating a fair fit. The half-life in 0–1 cm soil layer using the SFOK ranged from 9.0 to 11.0 days while it ranged from 3.3 to 4.1 days in water. The half-life of mefenacet in 0–1 cm soil was a bit shorter in 1996 compared to 1995 and 1997. In water, a little faster dissipation was observed in 1995 than in 1996 and 1997.

Dissipation in the 1–5 and 5–10 cm layers is shown in Figs. 5 and 6. Mefenacet was detected in all sampling days. At the 1–5 cm layer, in 1995, an abrupt increase in mefenacet concentration was observed at 7 DAHA
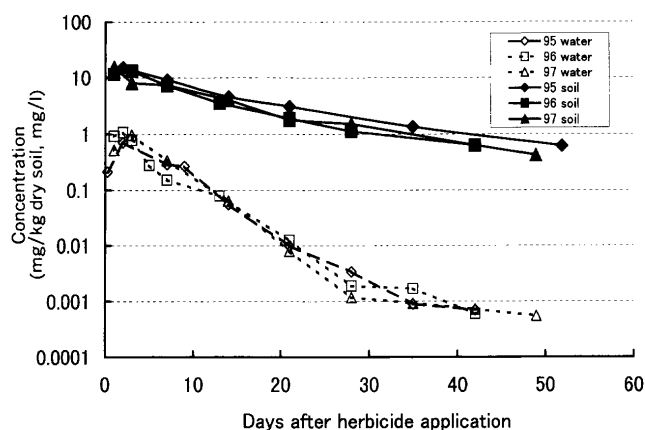

Fig. 4 Mefenacet dissipation in 0–1 cm layer paddy soil and in paddy water. NIAES Experiment Station, 1995–1997.

Table 2 Half life (DT$_{50}$), dissipation rate (k) and R^2 values for mefenacet in 0–1 cm soil layer and in paddy water, NIAES field station.

| Year | Simple first order kinetics 1 to 52 | | | Biphasic first order kinetics | | | | | |
| | | | | 1 to 21 | | | 21 up | | |
	k	R^2	DT$_{50}$	k	R^2	DT$_{50}$	k	R^2	DT$_{50}$
0–1 cm soil									
1995	0.0629	0.9758	11.0	0.0852	0.9835	8.1	0.0519	0.9942	13.4
1996	0.0770	0.9469	9.0	0.0999	0.9710	6.9	0.0503	0.9735	13.8
1997	0.0704	0.9699	9.8	0.0967	0.9543	7.2	0.0535	0.9815	13.0
Paddy water									
1995	0.2126	0.9915	3.3	0.2309	0.9788	3.0	0.1797	0.9925	3.9
1996	0.1867	0.9669	3.7	0.2206	0.9561	3.1	0.1314	0.8873	5.3
1997	0.1708	0.8997	4.1	0.2633	0.9978	2.6	0.0836	0.7574	8.3

Biphasic 1st order=two regression lines are used to describe the degradation of the herbicide, i.e., one for the 1st 3 weeks and another for the 3rd week onwards. DT$_{50}$=half life (in days); computed using the equation $-\ln(0.5)/k$. k=dissipation rate; slope of the regression line
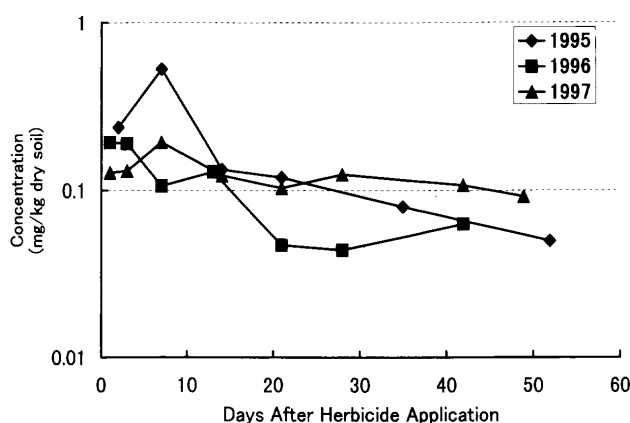
Fig. 5　Mefenacet dissipation in 1-5 cm layer in a paddy field. NIAES Experiment Station, 1995-1997.
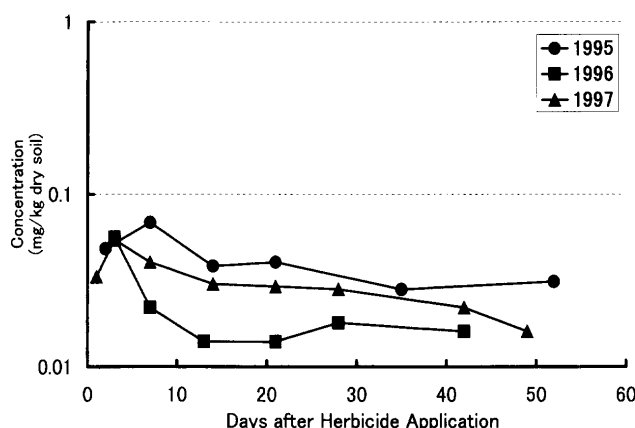

Fig. 6　Mefenacet dissipation in 5-10 cm layer in a paddy field. NIAES Experiment Station, 1995-1997.

while none was observed in 1996 and 1997. In all the 3 years, however, dissipation leveled off or decreased very slightly from the 14th day onwards.

At the 5-10 cm layer, slight decrease was observed only until 14 DAHA and appeared to have leveled off from the 21st day. Similar to pretilachlor, residues in soil or in water remained almost identical in all years.

DISCUSSION

Analysis of herbicide residues was subdivided into 0-1, 1-5 and 5-10 cm soil layers. Over 90% of the residues were in the topmost (0-1 cm) layer. In related trials, Sugiyama et al.[12] also reported that most of butachlor and pretilachlor residues were localized in the 0-1 cm layer. It therefore appears that computing the half-life based on the bulked 0-10 cm layer will actually give us the half-life in the 0-1 cm layer.

Mefenacet and pretilachlor have clearly different dissipation patterns at the 0-1 cm layer. Pretilachlor appears to follow a descending curvilinear pattern while mefenacet fits a descending linear pattern. For pretilachlor, using SFOK to calculate the half life at the 0-1 cm soil layer initially underestimates but ultimately overesti-

mates the degradation. Reyes and Zimdahl[13] had similar observations regarding trifluralin and, in turn, proposed the biexponential model that resulted from the integration of the first-order and second-order differential rate equations. LaFleur et al.[14] also suggested that a two-step or complex first order kinetics might provide a more suitable model for predicting residue dissipation. For mefenacet, on the other hand, the SFOK appeared to be sufficient for calculating the half-life in both paddy soil (0-1 cm) and in water.

In the 0-1 cm soil layer, the dissipation of pretilachlor was generally faster than mefenacet because the former has higher water solubility and slightly faster degradation rate. However, the pattern and rate of dissipation of both herbicides in the upper soil layer did not vary considerably across years. Laboratory measurements conducted by Takagi et al.[8,16] put the DT_{50} value of pretilachlor and mefenacet to be 18.8 and 20.2 days, respectively. The percolation rate (leaching) and outflow rate (runoff) of paddy water in the test field was 0.4 cm/day and 1.2 cm/day respectively. Desorption rate constant of pretilachlor (0.114/day) was almost twice as high as mefenacet (0.063/day).[8,16] The interaction between the faster desorption rate of pretilachlor and the leaching and runoff properties of the soil may have caused the quicker disappearance of pretilachlor.

Leaching was more noticeable in pretilachlor than in mefenacet. It could be partly due to the lower water solubility of mefenacet (4 mg/l) and higher adsorption coefficient ($K_d = 24.07$).[16] On the other hand, pretilachlor has higher water solubility (50 mg/l) and lower K_d value (13.03).[8,16] This may indicate that more pretilachlor, having higher water solubility and lower K_d value, was transported to the lower layers through the downward flow of water. Mefenacet is also strongly adsorbed in soil and therefore have little movement.[17,18]

The topmost layer, being in an oxidative (aerobic) condition[8] contains most of the soil microbes that aids in biodegradation. In addition to this, the topmost soil layer is exposed to other degradation factors such as photo-decomposition. Hence, herbicides in the 0-1 cm layer are affected by a greater number of factors than in the lower soil layers. As Roberts[21] pointed out, the major route of dissipation of chloroacetanilides is by microbial degradation. Under artificial or natural sunlight, minimal aqueous photolytic degradation occurs. Chloroacetanilides biodegrade very rapidly and extensively in soil and they are stable to hydrolytic degradation at pH (3-9) and temperature of less than 25°C.[21]

The amount of pretilachlor applied was lower than mefenacet, hence, the initial concentration at 1 DAHA was about 5 and 10 ppm, respectively. At about 21 DAHA, in the 0-1 cm soil layer, pretilachlor was about 0.1 ppm while mefenacet was greater than 1.0 ppm. During this period, pretilachlor dissipation started to

slow down while mefenacet showed no marked decrease in its dissipation rate. Mefenacet being in a much higher amount may have been more bio-available. Alexander[15] said that the evidence for reduced bio-availability of a compound is the marked decline in its degradation rate.

The dissipation rate of pretilachlor in all years at the 1–5 cm layer was rapid from 7 to 28 DAHA. Soil condition in the experimental plots started to be anaerobic (Eh at 3 cm≤ -150 mv) at about 10 DAHA.[7] Butachlor, under anaerobic field conditions, also dissipated very rapidly until 28 days after treatment and until 42 days after incubation under the same condition in the laboratory.[19] In earlier studies, rapid dechlorination of benthiocarb was observed to occur in flooded soils 7–10 days after its application[20]. Related reports involving alachlor and butachlor indicated that degradation accelerated under anaerobic conditions and that their reductive dehalogenation yielded acetanilide compounds.[21] Reductive degradation processes prevail in anaerobic soil zones and especially in flooded soils. From the ecotoxicological point of view, the most important reaction in a chlorinated molecule degradation is reductive dehalogenation.[22] Based on our observations in the field experiment, there was a possibility that pretilachlor could have been degraded by dechlorination in the reductive soil layers.

Generally, at the 1–5 cm layer, mefenacet dissipation appeared to have slowed down after 21 DAHA while it started to slow down after 14 DAHA at the 5–10 cm layer. This may be attributed to its low water solubility and higher K_d value[16] that allowed much of the herbicide molecules to be adsorbed by the soil. Compounds with low water solubility tend to adsorb onto soils and sediments.[23]

Although mefenacet had been already been applied to the same plot since 1990, there was no indication of residue build up nor changes in the rate and pattern of dissipation. The baseline data (0–10 cm layer) taken before the herbicide was applied were 0.025, 0.012 and 0.019 mg/kg dry soil in 1995, 1996 and 1997, respectively.

In paddy water, dissipation pattern was dissimilar between the two herbicides. However, the pattern for each herbicide was similar across years. The dissipation pattern of pretilachlor was a continuous curvilinear slope while for mefenacet dissipation was quick until 28 DAHA and then appeared to have stagnated afterwards. Mefenacet concentration peaked on the second to third day then dropped subsequently. This could be accounted to the differences in the dissolution rate of the herbicides, *i.e.*, the rate at which the herbicide molecules were released from its granular formulation. Pretilachlor was dissolved completely within 24 hrs while mefenacet took more than 2 days to be completely dissolved.[8]

Also, since mefenacet has lower water solubility, much of its residues could have been absorbed by the soil thus leaving only a small portion in water. The amount of mefenacet that remained in the 0–1 cm soil layer at 28 DAHA was still about 1 ppm compared to 0.01 ppm for pretilachlor. During that time on, the amount of mefenacet that was released into the water was stagnant while that of pretilachlor declined steadily.

At the lower soil layers (1–5 and 5–10 cm), where the condition was reductive and anaerobic[8], calculating the half-life using either SFOK or BFOK was inappropriate because of the bell-shaped trend in the dissipation pattern. In water, on the other hand, using the SFOK was sufficient to estimate the half-life of both herbicides.

The results of this study show that mefenacet and pretilachlor, although both acetanilide, have different behavior in paddy soil and water. Also, continuous use, of both herbicides did not cause build up of residues and as a result will not be a great threat as an environmental contaminant. As there are still very limited studies on the behavior of these herbicides in soil and water under lowland conditions, further research is needed to fully understand the nature of these compounds.

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要　　約

水田圃場の作土層と田面水中におけるプレチラクロールとメフェナセットの消失パターンと速度：3 年間の圃場実験

Ferdinand F. Fajardo, 高木和広
石坂眞澄, 臼井健二

1995 年～97 年までの 3 年間, 農環研水田圃場の田面水中と作土層中(0～1, 1～5, 5～10 cm)での除草剤プレチラクロール (PTC) とメフェナセット (MF) の消失パターンと速度を 5 月中旬～7 月初旬まで調査した. また, 各薬剤の圃場中での半減期を一次反応速度式(SFOK)と 2 段階の一次反応速度式(BFOK)を用いて計算した. 田面水と作土層中での PTC と MF の消失パターンと速度はかなり異なっていた. この原因としては, PTC の水溶解度が MF に比べ 10 倍以上高いことと PTC の土壌中 (特に還元層) での分解速度が MF に比べ速いことが考えられる. 最上層 0～1 cm(酸化層)では, PTC の消失速度は最初の 3 週間は速かったが, その後は速度が減速した. しかし, MF の場合, 調査期間中の消失速度はほぼ一定であった. 最上層での PTC と MF の半減期はそれぞれ 7～10 日, 9～11 日であった. 還元層である中・下層(1～5, 5～10 cm)では, 最上層の PTC がリーチングし, 散布後約 2 週目に最高濃度が検出され, その後急速に消失した. 一方, MF では, 中・下層へのリーチングは PTC ほど顕著ではなく, 一定速度で緩やかに消失した. 田面水中では, MF 濃度は散布 2～3 日後にピークに達した後急速に減少し, 4 週目以降消失速度は減速した. 一方, PTC 濃度は, 散布 1 日後にピークに達しその後一定速度で減少した. 田面水中での PTC と MF の半減期はそれぞれ 3.0～3.6 日, 3.3～4.1 日であった. 土壌中での薬剤消失速度を求める場合, 消失速度が一定である MF では, SFOK を用いて満足な結果を得れるが, 消失速度が変化する PTC では, BFOK を用いた方がより高精度の値を得ること出来る. 両薬剤の消失パターンと速度の調査年による違いは殆ど認められなかった.