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Adsorption, Desorption And Mobility Of Amides In Soils

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ABSTRACT

Experiments on adsorption, desorption and movement of diphenamid [N, N - dimethyl-2, 2-diphenylacetamide], metolachlor [2 chloro-*N*-(2-ethyl-6-methyl phenyl)-*N*-(2-methoxy-1-methyl-ethyl) acetamide], napropamide [2-(-naptoxy)-*N*, *N*-diethyl propionamide] and pretilachlor [2-chloro-2, 6-diethyl-*N*-(2-propoxyethyl)-acetanilide] were conducted in four commonly occurring soils of Central Thailand. The soils were Bang Khen clay (Bang Khen series), Pak Chong clay loam, (Pak Chong series) Kamphaeng Saen loam (Kamphaeng Saen series) and Sattahip loamy sand (Sattahip series). Organic carbon contents of the soils by weight varied from 0.56 to 2.75 percent and clay fraction ranged from 5 to 57 percent. Freundlich adsorption isotherms and distribution coefficient exhibited that amides were adsorbed in the order napropamide > pretilachlor > metolachlor > diphenamid. Rf values indicated the order of herbicide movement to be pretilachlor > diphenamid > metolachlor > napropamide. However, very high rate of pretilachlor movement occurred only in Kamphaeng Saen loam and Sattahip loamy sand. Furthermore, very small fraction of pretilachlor was mobile but the large fraction remained at the site of application. All herbicides were desorbed in all soil types. It was demonstrated that diphenamid and metolachlor were sufficiently mobile in soils low in organic carbon and clay content and could cause possible loss of efficacy or they could accumulate in ground water.

INTRODUCTION

Amide herbicides are widely used for weed control in various crops in Thailand. Diphenamid is used mainly in soybean, peanut, potatoes, tomatoes and tobacco. Napropamide is used mainly in potatoes, tomatoes and tobacco. Metolachlor is used mainly in corn, soybean and peanut. Pretilachlor is used in the combination with antidote in rice. Amides control a similar spectrum of weeds especially most of annual grasses and certain broadleaf weeds.

The activity of soil - applied herbicide is influenced by several soil properties. The soil fractions responsible for adsorption, desorption and mobility of herbicides also influence the degree of phytotoxicity of any specific herbicide. The soil mobility of herbicides of amide family varies widely. Harris (1964, 1967) reported that diphenamid was relatively mobile. In soil column, Dubey and Freeman (1965) found that diphenamid moved 20.0 centimeters in a sandy loam soil column. Deli and Warren (1971) concluded that the soil movement of diphenamid was reduced as the bentonite clay or organic matter content of soil increased.

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Wu *et al.* (1975) found that mobility of napropamide was reduced with an increase of clay and organic matter content. Napropamide was not as mobile as fluometuron but was slightly more mobile than terbutryn (Wu *et al.,* (1975). Furthermore, Wu and Santelman (1975) used different laboratory methods including thin layer, thick layer and column chromatography to compare the leaching of four herbicides. The order of mobility found was fluometuron > napropamide > terbutryn > trifluralin. Less herbicide mobility was observed in heavier soil than in sandy soil.

Obrigawitch *et al.* (1981) found that adsorption of metolachlor exhibited two linear regions for each soil, suggesting the possibility of multilayer adsorption. Freundlich K values indicated that organic matter was the predominant absorbent of metolachlor in the soils (Obrigawitch *et al.,* 1981). Moreover, desorption soil column, leaching and thin layer plates studies demonstrated metolachlor to be significantly mobile in soils low in organic matter to cause possible crop injury or less efficacy (Obrigawitch *et al.,* 1981). However, Weber and Peter (1982) reported that alachlor, acetochlor and metolachlor were adsorbed on montmorillonite clay and organic matter in similar amounts. Recently, Peter and Weber (1985) reported that adsorption of alachlor and metolachlor was possitively correlated with soil organic matter content, clay content and surface area and inversely correlated with herbicidal activity. Moreover, alachlor was adsorbed in a slightly greater amount than that of metolachlor by soil, therefore, a slightly greater amount of alachlor was retained in the upper soil zones compared with that of metolachlor.

The selectivity of some pre - emergence herbicides is based to some extent on relative placement of the herbicide and crop seed. Excessive precipitation may move the herbicide into the crop root zone, causing injury. For this reason, it is important to study the activity of herbicides in soils, especially in coarse - textured soils and soils low in organic matter. Behavior of amide herbicides in the soils was reported in the other countries. However, little information on the action of amides in the soils occurring in Thailand could be found. This study was undertaken to determine the activity and movement of diphenamid, metolachlor, napropamide and pretilachlor in four commonly occurring soils in Thailand.

MATERIALS AND METHODS

Adsorption - Desorption Experiments

The adsorption of four ^{14}C-labeled amide herbicides (Table 1) on four soils of Thailand (Table 2) were determined under room temperature (28 ± 2°C). One gram samples of soil sieved through a 2 millimeter mesh sieve were weighed in 10 milliter screw top vials. Solution containing 2,000 dpm/ml of ^{14}C-herbicide was prepared in 0.01 M. $CaCl_2$ along with non - labeled herbicide at 4, 8, 12, 16 and 20 μg/ml the concentration of the herbicide associated with its respective ^{14}C-herbicide. Aliquots (5.0 ml) of the herbicide solution were pipetted into the vials. The vials were capped and placed on a shaker for 24 hours. Preliminary studies showed that all chemicals reached equilibrium with soils after shaking for this period of time.

After shaking, the vials were centrifuged and a 1.0 milliliter aliquot of the supernatant liquid was placed in a scintillation vial with 4.5 milliliter of counting cock tail (60.0 g napthalene, 5.0 g PPO and 0.5 g POPOP per liter of dioxane). The quantity of herbicide adsorbed was determined by calculating the difference between the initial herbicide concentration (dpm/ml) and the concentration present in the equilibrium solution after the herbicide was adsorbed onto the soil. K values were determined by using the Freundlich equation. Each treatment was replicated four times in a completely randomized design.

The first step in the desorption process involved decantation of equilibrium solutions from the weighed tubes. The outside of the tubes was then wiped and the tubes were reweighed. Sufficient 0.01 M $CaCl_2$ solution was added to each tube to achieve the 1 : 5 ratio between soil and solution after correction for interstitial solution. The tubes and contents were shaken again and centrifuged as described above, then one milliliter aliquot was removed and counted at the end of a 24-hour equilibration period. Two desorptions were conducted. Each treatment was replicated four times in a completely randomized design.

Table 1 Properties of ^{14}C-herbicides.

Herbicides	Specific activity (μci/mg)	Label position	Water solubility (Anonymous, 1983) (ppm)
Metolachlor	26.3	ring	530
Diphenamid	13.3	carbonyl	260
Napropamide	36.4	ring	73
Pretilachlor	38.4	ring	50

Table 2 Soil chemical and physical properties.

Soils	pH	CEC (me/100g)	Organic carbon	Sand	Silt	Clay
			← (%)			→
Bang Khen clay (Bang Khen series)	5.6	25.7	2.75	17	26	57
Pak Chong clay loam (Pak Chong series)	6.8	15.3	1.90	23	40	37
Kamphaeng Saen loam (Kamphaeng Saen series)	6.0	6.4	1.04	47	36	17
Sattahip loamy sand (Sattahip series)	5.2	1.2	0.57	81	14	5

Mobility Experiments

Soil thin layer chromatography plate (TLC) was prepared by mixing each of soil type (Table 2) with sufficient water to form a paste. Glass plates, 20 × 20 centimeter were partitioned into 4 × 20 centimeter columns. The soil paste was spread over the plates and allowed to dry. After drying, four independent soil columns were obtained. Approximately 0.5 μ ci of the four ^{14}C-labeled herbicides (Table 1) was applied to their respective columns on the soil TLC plates at 3.0 centimeter from the bottom. The plates were placed in a TLC developing tank containing water at a depth of 1.0 centimeter. The plates were left in the tank until the water saturated the soil column at least 15.0 centimeter up the plate. The movement of water from the point of herbicide application to the position of the wetting front was recorded and the plates were allowed to dry. The dry plates were exposed to x-ray film for four weeks to trace the movement of ^{14}C-labeled herbicides. The movement of herbicides was compared by determining their retention factor (Rf). The Rf values can be calculated by dividing the distance of herbicide movement by the distance of water movement (solvent front). Each treatment was replicated four times in a completely randomized design.

RESULTS AND DISCUSSION

Soil Adsorption - Desorption Experiments

The amount of amide herbicides adsorption in four soils is described by Fruendlich isotherm in Table 3. The average K values across soil types indicated that the greatest amount of napropamide was adsorbed, followed by pretilachlor, metolachor and diphenamid respectively (Table 3). However, the average K values across the herbicide indicated that the greatest amount of herbicides were adsorbed by Bang Khen clay followed by Kamphaeng Saen loam, Pak Chong clay loam and Sattahip loamy sand respectively (Table 3). The adsorption sequence might be anticipated based on the organic carbon and clay content of the soils (Deli and Warren, 1971 ; Obrigawitch *et al.,* 1981 ; Wu *et al.,* 1975). However, greater amount of metolachlor and napropamide were adsorped by Kamphaeng Saen loam more than Pak Chong clay loam. Since Pak Chong clay loam contains more clay fraction and organic carbon than Kamphaeng Saen loam (Table 2) these adsorption sequence could not be explained by differential amount of organic carbon and clay content in each soil. But types of clay and organic carbon might affect metolachlor and napropamide adsorption which caused Kamphaeng Saen loam to adsorbed both herbicides more than Pak Chong clay loam did. However,(in Table 2) types of clay and organic carbon were not identified.

Freundlich adsorption constants were calculated on the whole soil and organic carbon bases (Table 4). K'oc is defined by the relationship.

$$K'oc = \frac{K \times 100}{\% C}$$

where K represents the Freundlich adsorption (Table 3) and C is the organic carbon content of the soil (Table 2). K'oc value of each herbicide (Table 4) depended on soil types. The average K'oc value across soil types of napropamide was highest followed by pretilachlor, metolachlor and diphenamid respectively. Low K'oc value of metolachlor in Bang Khen soil was probably due to the relatively higher clay content in the soil. The K'oc values of metolachlor and napropamide in Kamphaeng Saen loam were higher than the K'oc of these herbicides in Pak

Table 3 Freundlich K-values for herbicide adsorption onto four soils.

Soils	Herbicides				$\bar{x}$
	Diphenamid	Metolachlor	Napropamide	Pretilachlor	
	←		(K)	→	
Bang Khen clay	0.84 a[1]	1.19 b	3.95 a	2.73 a	2.18 a
Pak Chong clay loam	0.34 b	0.65 d	1.27 d	1.04 c	0.83 c
Kamphaeng Saen loam	0.13 c	1.44 a	1.58 c	0.81 d	0.99 b
Sattahip loamy sand	0.03 d	0.86 c	1.83 b	1.25 b	0.99 b
$\bar{x}$	0.34 D[2]	0.86 C	1.83 A	1.25 B	

[1] Means within a column followed by the same letter are not significantly different at the 5% level as determined by Duncan's multiple range test.

[2] Means within a line followed by the same letter are not significantly different at the 5% level as determined by Duncan's multiple range test.

Table 4 Freundlich adsorption constants and organic carbon bases (K'oc).

Soils	Herbicides				$\bar{x}$
	Diphenamid	Metolachlor	Napropamide	Pretilachlor	
	←		(K'oc)	→	
Bang Khen clay	30.5 a[1]	43.2 b	143.4 b	99.1 a	79.1 b
Pak Chong clay loam	17.9 b	34.2 c	66.8 d	54.7 c	43.4 c
Kamphaeng Saen loam	12.4 c	137.8 a	151.2 a	77.5 b	94.7 a
Sattahip loamy sand	5.2 d	24.6 d	87.7 c	71.9 b	47.4 c
$\bar{x}$	16.5 D[2]	59.9 C	112.3 A	75.8 B	-

[1] Means within a column followed by the same letter are not significantly different at the 5% level as determined by Duncan's maltiple range test.

[2] Means within a line followed by the same letter are not significantly different at the 5% level as determined by Duncan's maltiple range test.

Chong clay loam (Table 4). Furthermore the K'oc of napropamide and pretilachlor in Sattahip loamy sand were also higher than the K'oc of both herbicides in Pak Chong clay loam (Table 4). But the organic carbon content in Pak Chong clay loam was higher than Kamphaeng Saen loam and Sattahip loamy sand respectively (Table 2). This finding suggested that nature of organic carbon was important for napropamide, metolachlor and pretilachlor adsorption, particularly onto Kamphaeng Saen loam and Sattahip loamy sand.

Coefficient of determination (r^2) values were calculated for percent organic carbon and clay versus Freundlich adsorption constant (K) for the four soils. Percent organic carbon versus K values gave r^2 = 0.64, 0.71, 0.89 and 0.75 and percent clay versus K values gave r^2 = 0.64, 0.65, 0.89 and 0.75 for diphenamid, metolachlor, napropamide and pretilachlor respectively. Coefficient of determination values for diphenamid, napropamide and pretilachlor showed that organic carbon and clay fraction were equally important. However, it was shown that organic carbon was slightly more important than clay fraction for metolachlor adsorption. This result was supported by the report of Obrigawitch *et al.* (1981). A direct implication, therefore, was that metolachlor applied to soils low in organic carbon might be susceptible to redistribution within the soil profile.

The distribution coefficient (Kd) values of diphenamid in all soils were slightly changed with increasing herbicide solution concentration (Table 5). However, Kd values of metolachlor and pretilachlor were slightly changed in Bang Khen clay and Sattahip loamy sand but they decreased with increasing herbicide solution concentration in Pak Chong clay loam and Kamphaeng Saen loam. Kd values of napropamide were gradually decreased with increasing herbicide solution concentration in all soils. The variation of Kd values depended on the interaction between herbicides and soil types. The Kd values decreased with increasing herbicide solution concentration demonstrated the potential for herbicide leaching, particularly at the higher application rate.

All herbicides were desorbed in all soils (Table 6, 7, 8 and 9). After first and second desorption, the greatest amount of each herbicide remained on Bang Khen clay, followed by Pak Chong clay loam, Kamphaeng Saen loam and Sattahip loamy sand respectively (Tables 6, 7, 8 and 9). However, after first and second desorption the amount of metolachlor adsorbed on Pak Chong clay loam and Sattahip loamy sand was markedly reduced (Table 7). Therefore application of metolachlor in both soils might be susceptible to movement within the soil profile. Both desorptions of napropamide in Pak Chong clay loam and Kamphaeng Saen loam gradually increased with the increase of herbicide concentration (Tables 8 and 9).

Mobility Experiments

The average Rf values from soil thin layer plate across herbicides indicated that the most herbicide mobility occurred in Sattahip loamy sand followed by that of Kamphaeng Saen loam, Pak Chong clay loam and Bang Khen clay respectively (Table 10). The greatest movement of herbicides occurred in Sattahip loamy sand because of its low clay and organic matter content. Since clay and organic fraction were the adsorbent of amide herbicides (Deli and Warren, 1971 ; Obrigawitch *et al.,* 1981 ; Wu *et al.,* 1975) the lowest Rf value of Bang Khen clay was attributed to its higher organic matter and clay content compared with that of the other three soils. The movement of diphenamid

Table 5 Distribution coefficient (Kd) of amide herbicides in four soils.

Soils	Initial concentration (g/ml)	Herbicides (Kd) Diphenamid	Metolachlor	Napropamide	Pretilachlor
Bang Khen clay	4	0.94 (± 0.03)	1.18 (± 0.19)	3.92 (± 0.60)	2.70 (± 0.03)
	8	0.83 (± 0.10)	1.14 (± 0.08)	3.86 (± 0.32)	2.76 (± 0.49)
	12	0.89 (± 0.06)	0.84 (± 0.06)	3.40 (± 0.31)	2.86 (± 0.13)
	16	0.96 (± 0.13)	1.17 (± 0.04)	3.27 (± 0.34)	2.87 (± 0.16)
	20	1.11 (± 0.03)	1.17 (± 0.06)	3.41 (± 0.67)	2.81 (± 0.11)
Pak Chong clay loam	4	0.33 (± 0.06)	0.50 (± 0.02)	1.07 (± 0.04)	0.88 (± 0.03)
	8	0.28 (± 0.03)	0.52 (± 0.02)	0.95 (± 0.03)	0.86 (± 0.09)
	12	0.28 (± 0.02)	0.32 (± 0.01)	0.91 (± 0.06)	0.69 (± 0.09)
	16	0.28 (± 0.01)	0.38 (± 0.01)	0.80 (± 0.07)	0.72 (± 0.03)
	20	0.30 (± 0.01)	0.38 (± 0.02)	0.71 (± 0.04)	0.66 (± 0.02)
Kamphaeng Saen loam	4	0.13 (± 0.01)	0.88 (± 0.05)	1.16 (± 0.10)	0.71 (± 0.07)
	8	0.15 (± 0.01)	0.46 (± 0.04)	0.87 (± 0.06)	0.64 (± 0.05)
	12	0.17 (± 0.01)	0.30 (± 0.02)	0.64 (± 0.03)	0.55 (± 0.03)
	16	0.12 (± 0.01)	0.27 (± 0.03)	0.66 (± 0.04)	0.57 (± 0.05)
	20	0.16 (± 0.01)	0.23 (± 0.01)	0.45 (± 0.03)	0.54 (± 0.03)
Sattahip loamy sand	4	0.05 (± 0.03)	0.12 (± 0.01)	0.39 (± 0.02)	0.36 (± 0.03)
	8	0.04 (± 0.01)	0.19 (± 0.03)	0.30 (± 0.04)	0.35 (± 0.04)
	12	0.04 (± 0.00)	0.18 (± 0.02)	0.26 (± 0.01)	0.31 (± 0.04)
	16	0.06 (± 0.01)	0.13 (± 0.01)	0.28 (± 0.02)	0.31 (± 0.03)
	20	0.07 (± 0.02)	0.15 (± 0.01)	0.24 (± 0.00)	0.32 (± 0.04)

Table 6 Adsorbed diphenamid on soils and the following desorption.

Soils	Initial concentration (μg/ml)	Adsorption (μg/g)	1st desorption (μg/g)	2nd desorption (μg/g)
Bang Khen	4	1.9 (± 0.06)	0.8 (± 0.02)	0.3 (± 0.009)
clay	8	3.6 (± 0.04)	1.3 (± 0.15)	0.3 (± 0.04)
	12	5.6 (± 0.37)	2.1 (± 0.14)	0.4 (± 0.26)
	16	7.8 (± 1.05)	3.2 (± 0.43)	1.0 (± 0.13)
	20	10.5 (± 0.28)	4.0 (± 0.10)	2.3 (± 0.06)
Pak Chong	4	1.0 (± 0.18)	0.4 (± 0.07)	0.1 (± 0.01)
clay loam	8	1.7 (± 0.07)	0.6 (± 0.06)	0.1 (± 0.01)
	12	2.6 (± 0.18)	1.2 (± 0.08)	0.4 (± 0.02)
	16	3.5 (± 0.12)	1.3 (± 0.04)	0.2 (± 0.007)
	20	4.6 (± 0.15)	2.0 (± 0.06)	0.7 (± 0.02)
Kamphaeng Saen	4	0.5 (± 0.03)	0.2 (± 0.01)	< 0.1 (± 0.007)
loam	8	1.0 (± 0.06)	0.4 (± 0.02)	0.1 (± 0.006)
	12	1.7 (± 0.1)	0.4 (± 0.02)	0.1 (± 0.005)
	16	1.7 (± 0.14)	0.5 (± 0.04)	0.6 (± 0.005)
	20	2.1 (± 0.13)	0.6 (± 0.03)	0.7 (± 0.04)
Sattahip	4	0.2 (± 0.12)	0.1 (± 0.06)	< 0.1 (± 0.01)
loamy sand	8	0.3 (± 0.07)	0.1 (± 0.05)	< 0.1 (± 0.05)
	12	0.4 (± 0.001)	0.2 (± 0.001)	0.1 (± 0.001)
	16	0.9 (± 0.14)	0.2 (± 0.03)	0.1 (± 0.01)
	20	1.4 (± 0.4)	0.3 (± 0.08)	0.1 (± 0.02)

Table 7 Adsorbed metolachlor on soils and following desorption.

Soils	Initial concentration (μg/ml)	Adsorption	1st desorption	2nd desorption
		←	(μg/g)	→
Bang Khen clay	4	2.2 (± 0.35)	1.2 (± 0.19)	0.7 (± 0.01)
	8	4.3 (± 0.30)	2.4 (± 0.17)	1.4 (± 0.09)
	12	5.5 (± 0.39)	2.5 (± 0.17)	1.1 (± 0.07)
	16	8.6 (± 0.29)	4.7 (± 0.15)	3.1 (± 0.1)
	20	10.8 (± 0.55)	6.2 (± 0.31)	3.9 (± 0.19)
Pak Chong clay loam	4	1.3 (± 0.005)	0.5 (± 0.002)	0.2 (± 0.01)
	8	2.7 (± 0.10)	1.1 (± 0.04)	0.5 (± 0.01)
	12	2.9 (± 0.08)	0.7 (± 0.02)	<0.1 (± 0.003)
	16	4.4 (± 0.11)	1.3 (± 0.03)	3.0 (± 0.07)
	20	5.5 (± 0.29)	1.8 (± 0.09)	0.5 (± 0.02)
Kamphaeng Saen loam	4	1.9 (± 0.1)	1.2 (± 0.06)	0.1 (± 0.05)
	8	2.5 (± 0.21)	1.2 (± 0.10)	0.4 (± 0.03)
	12	2.8 (± 0.18)	1.1 (± 0.04)	0.6 (± 0.04)
	16	3.4 (± 0.37)	0.8 (± 0.08)	0.2 (± 0.02)
	20	3.7 (± 0.15)	1.0 (± 0.4)	0.3 (± 0.01)
Sattahip loamy sand	4	0.4 (± 0.03)	0.2 (± 0.09)	0.1 (± 0.008)
	8	1.3 (± 0.2)	0.5 (± 0.07)	0.3 (± 0.04)
	12	1.9 (± 0.21)	1.0 (± 0.13)	0.8 (± 0.08)
	16	1.8 (± 0.13)	0.4 (± 0.03)	0.1 (± 0.007)
	20	2.5 (± 0.16)	0.5 (± 0.03)	0.2 (± 0.01)

Table 8 Adsorbed napropamide on soils and following desorption.

Soils	Initial concentration (μg/ml)	Adsorption	1st desorption	2nd desorption
		←	(μg/g)	→
Bang Khen clay	4	3.2 (± 0.48)	1.7 (± 0.38)	1.4 (± 0.32)
	8	6.3 (± 0.52)	3.4 (± 0.41)	2.8 (± 0.34)
	12	9.3 (± 0.84)	5.1 (± 0.65)	3.9 (± 0.52)
	16	12.2 (± 1.26)	6.7 (± 0.98)	5.4 (± 0.82)
	20	15.4 (± 3.01)	8.5 (± 2.33)	6.2 (± 1.90)
Pak Chong clay loam	4	2.1 (± 0.07)	1.2 (± 0.04)	0.8 (± 0.02)
	8	3.9 (± 0.12)	2.2 (± 0.07)	1.3 (± 0.04)
	12	5.7 (± 0.37)	3.2 (± 0.21)	1.9 (± 0.12)
	16	7.1 (± 0.61)	3.8 (± 0.33)	2.0 (± 0.17)
	20	8.3 (± 0.46)	3.5 (± 0.19)	1.0 (± 0.05)
Kamphaeng Saen loam	4	2.1 (± 0.18)	1.4 (± 0.12)	0.6 (± 0.08)
	8	3.7 (± 0.25)	2.1 (± 0.14)	1.4 (± 0.09)
	12	4.7 (± 0.22)	2.5 (± 0.11)	1.5 (± 0.07)
	16	6.4 (± 0.02)	3.6 (± 0.21)	2.3 (± 0.14)
	20	6.2 (± 0.41)	2.5 (± 0.16)	0.9 (± 0.06)
Sattahip loamy sand	4	1.1 (± 0.05)	0.4 (± 0.02)	0.1 (± 0.005)
	8	1.8 (± 0.23)	0.6 (± 0.07)	0.1 (± 0.01)
	12	2.5 (± 0.09)	0.7 (± 0.02)	0.2 (± 0.007)
	16	3.5 (± 0.24)	1.2 (± 0.08)	0.7 (± 0.04)
	20	3.6 (± 0.003)	1.2 (± 0.001)	0.4 (± 0.0001)

Table 9 Adsorbed pretilachlor on soils and following desorption.

Soils	Initial concentration (μg/ml)	Adsorption	1st desorption	2nd desorption
		←	(μg/g)	→
Bang Khen clay	4	2.9 (± 0.03)	1.6 (± 0.02)	1.0 (± 0.02)
	8	5.8 (± 0.48)	3.4 (± 0.81)	1.9 (± 0.56)
	12	8.9 (± 0.40)	4.8 (± 0.31)	3.7 (± 0.26)
	16	11.9 (± 0.66)	6.4 (± 0.51)	5.1 (± 0.43)
	20	14.7 (± 0.57)	7.9 (± 0.44)	6.5 (± 0.38)
Pak Chong clay loam	4	1.9 (± 0.06)	1.1 (± 0.03)	0.7 (± 0.02)
	8	3.7 (± 0.38)	2.2 (± 0.23)	1.5 (± 0.15)
	12	4.9 (± 0.63)	2.6 (± 0.33)	1.5 (± 0.19)
	16	6.7 (± 0.28)	3.5 (± 0.14)	2.0 (± 0.08)
	20	8.0 (± 0.24)	4.1 (± 0.12)	2.3 (± 0.06)
Kamphaeng Saen loam	4	1.7 (± 0.16)	0.9 (± 0.08)	0.6 (± 0.05)
	8	3.1 (± 0.24)	1.7 (± 0.13)	1.1 (± 0.08)
	12	4.3 (± 0.23)	2.2 (± 0.11)	1.3 (± 0.07)
	16	5.8 (± 0.51)	3.1 (± 0.27)	2.1 (± 0.18)
	20	7.0 (± 0.38)	3.8 (± 0.20)	2.6 (± 0.14)
Sattahip loamy sand	4	1.1 (± 0.09)	0.5 (± 0.04)	0.3 (± 0.02)
	8	2.1 (± 0.23)	1.0 (± 0.11)	0.6 (± 0.06)
	12	2.8 (± 0.36)	1.1 (± 0.14)	0.6 (± 0.07)
	16	3.7 (± 0.24)	1.6 (± 0.10)	0.9 (± 0.06)
	20	4.8 (± 0.60)	2.2 (± 0.27)	1.3 (± 0.16)

in Kamphaeng Saen loam was equal to that in Sattahip loamy sand. The most metolachlor movement was found in Kamphaeng Saen loam, followed by Sattahip loamy sand, Pak Chong clay loam and Bang Khen clay respectively. However, Rf values of metolachlor were comparable between that of Kamphaeng Saen loam and Sattahip loamy sand. The Rf value of pretilachlor in Sattahip loamy sand was approximately 2, 3 and 4.5 times greater than that in Kamphaeng Saen loam, Pak Chong clay loam and Bang Khen clay respectively. Therefore, the average Rf value across soil types demonstrated the order of herbicides movement within soil as pretilachlor > diphenamid > metolachlor > napropamide. However very small fraction of pretilachlor was mobile but the main portion remained at the site of application. Difference in mobility of amides might be attributed to difference in their water solubility (Table 1).

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Table 10 Movement of herbicides in four soils.

Soils	Herbicides				$\bar{x}$
	Diphenamid	Metolachlor	Napropamide	Pretilachlor	
	←		(Rf)		→
Bang Khen clay	0.14 c[1]	0.14 d	0.14 d	0.20 d	0.16 d
Pak Chong clay loam	0.35 b	0.31 c	0.18 c	0.29 c	0.28 c
Kamphaeng Saen loam	0.52 a	0.42 a	0.21 b	0.43 b	0.39 b
Sattahip loamy sand	0.52 a	0.38 b	0.28 a	0.89 a	0.51 a
$\bar{x}$	0.38 B[2]	0.31 C	0.20 D	0.45 A	

[1] Means within a column followed by the same letter are not significantly different at the 5% level as determined by Duncan's multiple range test.

[2] Means within a line followed by the same letter are not significantly different at the 5% level as determined by Duncan's multiple range test.

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