Insecticidal Activity of Alkanamides against Immature Mosquitoes

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3-Methylalkanamides, 2-alkylalkanamides, 2-haloalkanamides, straight-chain alkanamides, and their *N*-methyl, *N*-isobutyl, and *N,N*-dimethyl derivatives were prepared and evaluated for their insecticidal activity against the immature stages of *Culex pipiens quinquefasciatus* Say. Certain structural requirements became known to be essential for the amides to manifest larvicidal activity against the first-instar larvae of the mosquito. In primary amides, a methyl substituent must be present at the 3-position of the carbon chain. When an alkyl group is attached to the 2-position of the carbon chain, the amides must be tertiary; however, the resulting *N,N*-dimethyl-2-alkylalkanamides were only moderately active. For high activitiy, tertiary amides must not have any substituents attached to the carbon chain, and the length of the carbon chain of the straight-chain tertiary amides must be between C_{13} and C_{18}. Some straight-chain *N,N*-dimethylalkanamides demonstrated a wide spectrum of insecticidal activity affecting the development and survival of all stages of immature mosquitoes. Branched-chain alkanamides, on the other hand, had a narrow spectrum of activity influencing only the very young larvae.

A number of insecticidal isobutyl amides of unsaturated, aliphatic, straight-chain carboxylic acids having 10–18 carbon atoms have been isolated from plants of the families Compositae and Rutaceae (Jacobson, 1971). Among these isobutyl amides, spilanthol (*N*-isobutyl-2,6,8-decatrienamide), isolated from *Spilanthes oleraceae* Jacq., was reported to be toxic to *Anopheles* mosquito larvae (Jacobson, 1957). Affinin, isolated from *Heliopsis longipes* (A. Gray) Blake and later shown to be the same compound as spilanthol, caused a knockdown effect on the females of the yellow fever mosquito *Aedes aegypti* (L.) (Jacobson, 1971). *N*-(2-Methylpropyl)-(*E,E*)-2,4-decadienamide, isolated from *Achillea millefolium* L., was reported to induce 46 and 98% mortalities at 3 and 5 ppm, respectively, against 24-h-old *Aedes triseriatus* (Say) larvae (LaLonde et al., 1980). These studies suggested that some alkenamides possessed insecticidal activity.

During the course of our efforts in search of active analogues of larvicidal straight-chain and branched-chain alkanoic acids (Hwang and Mulla, 1976a; Hwang et al., 1974a,b, 1976, 1978a,b), we independently found that some alkanamides exhibited toxicity against immature *Culex pipiens quinquefasciatus* Say. These findings prompted us to synthesize amides, *N*-methyl amides, *N,N*-dimethyl amides, and *N*-isobutyl amides of various straight-chain and branched-chain aliphatic carboxylic acids for biological studies. Here we report the biological activity and the structure–activity relationship of alkanamides against various instars of preimaginal *C. pipiens quinquefasciatus*.

MATERIALS AND METHODS

The branched-chain alkanoic acids were prepared according to Hwang et al. (1974a,b, 1976, 1978a,b). The straight-chain aliphatic carboxylic acids were obtained from commercial sources. Both branched-chain and straight-chain alkanamides were synthesized as follows.

An alkanoic acid (3 g) was allowed to react with boiling thionyl chloride (20 mL) for 1.5 h. The excess thionyl chloride was removed by evaporation. The resulting alkanoyl chloride was added dropwise into stirred ammonium hydroxide (28%, 20 mL), aqueous methylamine (40%, 20 mL), or aqueous dimethylamine (40%, 20 mL). The mixture was stirred for 4 h. The alkanamide thus formed was collected by filtration or by solvent extraction. The crude product was recrystallized from acetone or distilled in vacuo. In preparing isobutyl amides, the alkanoyl chloride was added dropwise into a stirred solution of isobutylamine (10 mL) in ether or benzene (150 mL). The mixture was stirred for 4 h and washed with diluted HCl (2 N, 3 × 20 mL) and water (3 × 20 mL). After being dried over sodium sulfate, the ether or benzene solution was evaporated. The residual *N*-isobutylalkanamide was recrystallized from acetone.

All melting points and boiling points were uncorrected. All substituted alkanamides are racemates; for convenience, the prefix *dl* is omitted here. All spectrometric data accorded with the structures of the products and are shown as follows. The primary amides: IR (nujol) 3400, 3200 (NH_2), and 1660 cm^{-1} (C=O); ^1H NMR ($CDCl_3$) δ 5.84 (s, NH_2), 2.19 (t, CH_2CO), 1.28 (m, CH_2), and 0.81 ppm (t, CH_3). The *N*-methyl amides: IR (nujol) 3300 (NH), 1640 (C=O, amide I), 1560 (amide II), 1300 (amide III), and 720 cm^{-1} (amide V); ^1H NMR (CCl_4) δ 7.21 (s, NH), 2.63 (d, NCH_3), 2.02 (t, CH_2CO), 1.22 (m, CH_2), and 0.81 ppm (t, CH_3). The *N*-isobutyl amides: IR (nujol) 3300 (NH), 1640 (C=O, amide I), 1560 (amide II), 1280 (amide III), and 730 cm^{-1} (amide V); ^1H NMR (CCl_4) δ 5.50 (s, NH), 3.55 (m, CH), 2.93 (t, NCH_2), 2.00 (t, CH_2CO), 1.20 (m, CH_2), and 0.87 ppm (m, CH_3). The *N,N*-dimethyl amides: IR (nujol) 1650 cm^{-1} (C=O); ^1H NMR (CCl_4) δ 2.86 (d, NCH_3), 2.19 (t, CH_2CO), 1.30 (m, CH_2), and 0.88 ppm (t, CH_3).

The alkanamides were bioassayed against the first and fourth instar larvae and the pupae of *C. pipiens quinquefasciatus* as reported elsewhere (Hwang et al., 1974a). The bioassay data, obtained as percent mortalities at various concentrations, were analyzed for the log-probit regression analysis with a Compucorp Model 145E computer. The insecticidal activity of the test compounds was expressed in terms of lethal concentration in parts per million affecting 50 and 90% of the population (LC_{50} and LC_{90}).

RESULTS AND DISCUSSION

The first group of amides synthesized and evaluated consisted of 3-methylalkanamides and their *N*-isobutyl, *N*-methyl, and *N,N*-dimethyl derivatives (Table I). The primary amides of this type invariably showed a high level of larvicidal activity against the first instars of the mosquito. The highly active primary amides included 3-methyltetradecanamide (**1**), 3-methylheptadecanamide (**2**), 3-methyloctadecanamide (**3**), 3-methylnonadecanamide (**4**),

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Table I. Insecticidal Activity (ppm) of 3-Methylalkanamides against the First Instars of the Mosquito *C. pipiens quinquefasciatus*

	CH_3 | $RCHCH_2CONR_1R_2$						
compd	R	R_1	R_2	mp, °C	LC_{50}	LC_{90}	slope[a]
primary							
1	n-$C_{11}H_{23}$	H	H	88-88.5	0.67	1.18	5.24
2	n-$C_{14}H_{29}$	H	H	90-92	0.22	0.52	3.45
3	n-$C_{15}H_{31}$	H	H	90-92	0.60	0.87	7.75
4	n-$C_{16}H_{33}$	H	H	94.5-96	0.16	0.33	3.94
5	n-$C_{17}H_{35}$	H	H	88-91	0.52	0.93	5.08
secondary							
6	n-$C_{11}H_{23}$	i-C_4H_9	H	59-62	6.33	>10	0.65
7	n-$C_{15}H_{31}$	i-C_4H_9	H	79-79.5	>10	>10	
8	n-$C_{10}H_{21}$	i-C_4H_9	H	81-83	>10	>10	
9	n-$C_{16}H_{33}$	CH_3	H	83-84	>10	>10	
10	n-$C_{17}H_{35}$	CH_3	H	80-81.5	>10	>10	
tertiary							
11	n-$C_{16}H_{33}$	CH_3	CH_3	37-39	5.08	9.92	4.40
12	n-$C_{17}H_{35}$	CH_3	CH_3	38-40	>10	>10	

[a] Slope of probit regression line.

and 3-methyleicosanamide (5). 3-Methylnonadecanamide (4) displayed the highest activity among this group of amides.

In our previous studies on the larvicidal activity of 3-methylalkanoic acids and alkyl 3-methylalkanoates (Hwang et al., 1978a), we reported that 3-methyl-substituted carboxylic acids and esters from C_{17} to C_{20} generally exhibited a high degree of activity. A comparison of the larvicidal activity (LC_{50}) of the acids, esters, and amides is shown in Figure 1. The activity trend of the 3-methylalkanamides followed that of the 3-methylalkanoic acids, the latter being more active. The activity, in general, declined in the order of acids, methyl esters, amides, ethyl esters, and isopropyl esters. Among the groups of compounds in Figure 1, those having C_{19} in the main chain were invariably the most active ones.

The secondary amides of 3-methylalkanoic acids consisted of both methyl and isobutyl amides (Table I). Except for slightly active *N*-isobutyl-3-methyltetradecanamide (6), all secondary amides prepared did not show any measurable larvicidal activity within the concentrations used. Although a number of unsaturated isobutyl amides are known to manifest insecticidal activity (Jacobson, 1971), their activity against mosquito larvae was not thoroughly investigated. Additionally, because of the differences in evaluation procedures and in the species of mosquitoes used, it was difficult to compare the larvicidal activity of the saturated isobutyl amides reported here with that of the unsaturated isobutyl amides reported by others.

N,N-Dimethyl-3-methylnonadecanamide (11) showed moderate activity whereas *N,N*-dimethyl-3-methyleicosanamide (12) did not show any appreciable activity. From the structure–activity relationship of 3-methylalkanamides and their *N*-alkyl and *N,N*-dialkyl derivatives shown in Table I and discussed above, it is apparent that only primary amides possess a high level of insecticidal activity against the first instar larvae.

Previously, we reported that 2-ethyl, 2-butyl, and 2-hexylalkanoic acids having even numbers of carbon atoms and a total number of carbon atoms from 14 to 18 generally showed a moderate degree of activity (Hwang et al., 1974b). Odd-numbered 2-alkylalkanoic acids, such as 2-ethylheptadecanoic acid and 2-ethylnonadecanoic acid, were reported to exhibit a high degree of activity (Hwang and Mulla, 1979).

In the present study, primary (2-alkylalkanamides), secondary (*N*-methyl-2-alkylalkanamides), and tertiary

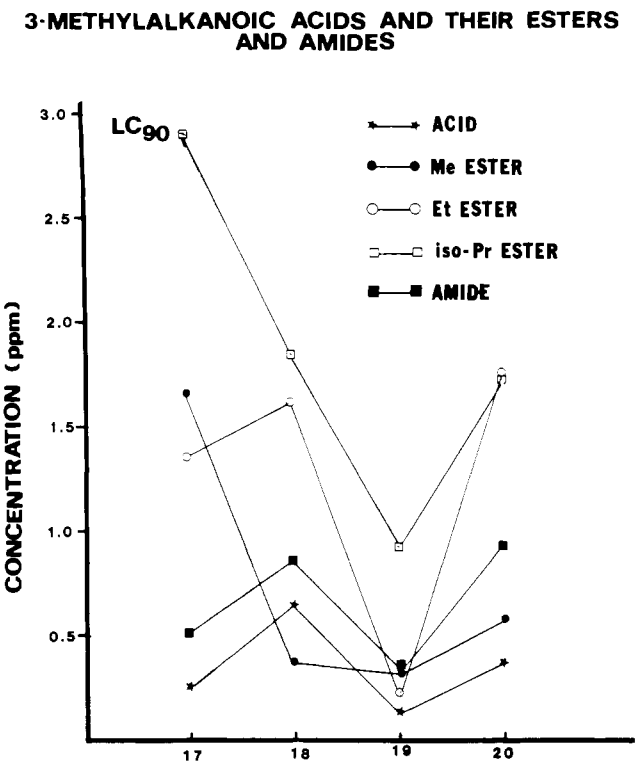


Figure 1. A comparison of the larvicial activity of 3-methylalkanoic acids, methyl, ethyl, and isopropyl 3-methylalkanoates, and 3-methylalkanamides against the first instars of the mosquito *C. pipiens quinquefasciatus*.

(*N,N*-dimethyl-2-alkylalkanamides) amides were prepared from the 2-alkylalkanoic acids and evaluated against the first instars of *C. pipiens quinquefasciatus*. None of the primary and secondary amides displayed any significant activity at 10 ppm, the highest concentration used for evaluation.

Some of the *N,N*-dimethyl-2-alkylalkanamides, however, showed larvicidal activity (Table II). They were *N,N*-dimethyl-2-ethylhexadecanamide (13), *N,N*-dimethyl-2-butyltetradecanamide (15), and *N,N*-dimethyl-2-butylhexadecanamide (16). All of them had lower molecular weights than the inactive tertiary amides 14, 17, and 18 and were liquid at the ambient temperature.

Table II. Insecticidal Activity (ppm) of *N,N*-Dimethyl-2-alkylalkanamides against the First Instars of the Mosquito *C. pipiens quinquefasciatus*

	$R_1RCHCON(CH_3)_2$						
compd	R	R_1	mp, °C	bp, °C (mm)	LC_{50}	LC_{90}	slope[a]
13	n-$C_{14}H_{29}$	C_2H_5		185 (0.5)	0.63	0.91	8.19
14	n-$C_{17}H_{35}$	C_2H_5	30-31		>10	>10	
15	n-$C_{12}H_{25}$	n-C_4H_9		187-188 (0.5)	0.91	1.27	8.83
16	n-$C_{14}H_{29}$	n-C_4H_9		199 (0.6)	3.18	6.74	3.92
17	n-$C_{18}H_{37}$	n-C_4H_9	38-40		>10	>10	
18	n-$C_{16}H_{33}$	n-C_6H_{13}	30.5-31		>10	>10	

[a] Slope of probit regression line.

Table III. Insecticidal Activity (ppm) of *N,N*-Dimethylalkanamides against the First Instars of the Mosquito *C. pipiens quinquefasciatus*

compd	$RCON(CH_3)_2$, R	mp, °C	bp, °C	LC_{50}	LC_{90}	slope[a]
19	n-C_9H_{19}		111-113 (0.45)	5.33	7.39	9.00
20	n-$C_{10}H_{21}$		135-141 (1.3)	1.71	2.20	11.73
21	n-$C_{11}H_{23}$		134-135 (0.5)	0.81	1.10	9.75
22	n-$C_{12}H_{25}$		148-190 (0.35)	0.18	0.41	3.73
23	n-$C_{13}H_{27}$	27-28		0.17	0.33	4.69
24	n-$C_{14}H_{29}$	33-35		0.26	0.39	7.36
25	n-$C_{15}H_{31}$	38-39		0.16	0.24	7.40
26	n-$C_{16}H_{33}$	45-47		0.29	0.52	4.98
27	n-$C_{17}H_{35}$	46-47		0.34	0.49	7.90
28	n-$C_{18}H_{37}$	51-52.5		>10	>10	
29	n-$C_{19}H_{39}$	54-56		>10	>10	
30	n-$C_{20}H_{41}$	56-58		>10	>10	
31	n-$C_{21}H_{43}$	58.5-60.5		>10	>10	

[a] Slope of probit regression line.

Table IV. Insecticidal Activity (ppm) of Various Acids, Esters, and Amides against the First Instars, the Fourth Instars, and the Pupae of the Mosquito *C. pipiens quinquefasciatus*

	1st		4th		pupae	
compd	LC_{50}	LC_{90}	LC_{50}	LC_{90}	LC_{50}	LC_{90}
32, n-$C_{14}H_{29}CH(CH_3)CH_2CO_2H$	0.09[a]	0.25[a]	2.60	20.57		
33, n-$C_{15}H_{31}CH(CH_3)CH_2CO_2H$	0.20[b]	0.70[b]	3.00[b]	25.00[b]		
34, n-$C_{14}H_{29}CH(CH_3)CH_2CO_2CH_3$	1.13[a]	1.67[a]	>20	>20		
35, n-$C_{15}H_{31}CH(CH_3)CH_2CO_2CH_3$	0.15[a]	0.38[a]	>20	>20		
3, n-$C_{15}H_{31}CH(CH_3)CH_2CONH_2$	0.60	0.87	>8	>8	>8	>8
21, n-$C_{11}H_{23}CON(CH_3)_2$	0.81	1.10	3.90	5.90	>10	>10
22, n-$C_{13}H_{25}CON(CH_3)_2$	0.18	0.41	3.30	5.20	3.40	5.20
23, n-$C_{13}H_{27}CON(CH_3)_2$	0.17	0.33	2.30	3.10	2.80	4.10

[a] Hwang et al. (1978a). [b] Hwang et al. (1974a).

Previously, we reported that 2-bromoalkanoic acids from C_{14} to C_{18} and methyl 2-bromoalkanoates from C_{10} to C_{18} showed moderate or high degrees of larvicidal activity (Hwang and Mulla, 1976a). Some halooctadecanoic acids and their methyl, ethyl, and isopropyl esters also manifested larvicidal activity (Hwang et al., 1978b). In the present studies, 2-chloro-, 2-bromo-, and 2-iodooctadecanamides and their *N*-methyl and *N,N*-dimethyl derivatives were prepared and bioassayed. However, none of the halogen-substituted amides showed any activity at or below 10 ppm.

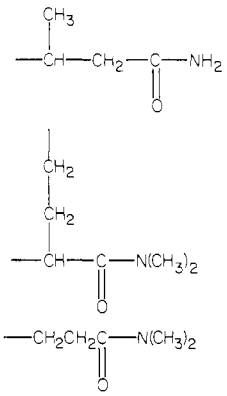
Maw (1970) reported that decanoic acid showed larvicidal activity, at 150 and 300 ppm, against *C. restuans* Theobald. LaLonde et al. (1979) reported that the LD_{50} of decanoic, dodecanoic, and tetradecanoic acids were 14, 7, and 4 ppm, respectively, against the young larvae of *Aedes triseriatus* (Say). Ikeshoji and Mulla (1974), however, found that nonanoic, decanoic, dodecanoic, hexadecanoic, and octadecanoic acids, at 9 ppm, caused less than 7% mortality in the first instars of *C. pipiens quinquefasciatus*.

In our present studies, the primary amides of straight-chain aliphatic carboxylic acids from C_{10} to C_{18} did not show any larvicidal activity at or below 10 ppm against the first instars of *C. pipiens quinquefasciatus*. Additionally, butyramide, the simplest amide evaluated, also exhibited no activity. The secondary amides of straight-chain carboxylic acids from C_{10} to C_{18}, including both *N*-methyl amides and *N*-isobutyl amides, did not display any activity either. *N*-Phenyl amides, such as *N*-phenylhexadecanamide, were also inactive.

The tertiary amide of straight-chain carboxylic acids, on the other hand, showed larvicidal activity against the first instars of *C. pipiens quinquefasciatus* (Table III). The first amide, *N,N*-dimethyldecanamide (**19**) showed moderate activity. The next two amides, *N,N*-dimethylundecanamide (**20**) and *N,N*-dimethyldodecanamide (**21**), became more active than their lower homologue. As the chain length extended further, the amides became more active. Thus, *N,N*-dimethyltridecanamide (**22**), *N,N*-dimethyltetradecanamide (**23**), and *N,N*-dimethylpentadecanamide (**24**) showed increased activity. The larvicidal activity of *N,N*-dimethylhexadecanamide (**25**) was the greatest with an LC_{50} and an LC_{90} of 0.16 and 0.24 ppm, respectively. The next two higher homologues, *N,N*-dimethylheptadecanamide (**26**) and *N,N*-dimethyloctadecanamide (**27**), were as active as amides **22**, **23** and **24**. When the chain length became longer, the larvicidal activity of the tertiary alkanamides abruptly decreased. *N,N*-Dimethylnonadecanamide (**28**) and its higher homologues, amides **29**, **30**, and **31**, did not show any appreciable activity at or under the 10-ppm concentration. It has been

known that, in a homologous series, each member is usually found to be more biologically active than its lower homologue until, suddenly, the addition of just one more CH_2 group severely diminishes, or even abolishes, the biological effect. Albert (1979) contends that toxicity should increase as a series is ascended because of increasing the absorptive factors which bind each substance to the organism's receptors with no increase in the desorptive forces. The sudden diminution or abolition of activity is caused by the solubility factor. When the lethal concentration of a compound in a series exceeds its solubility, a sharp cut-off of biological activity occurs (Ferguson, 1939).

From these structure–activity relationship studies on aliphatic amides, we conclude that there are certain structural requirements for the amides to manifest larvicidal activity. In a primary amide, a methyl substituent must be present at the 3-position of the carbon chain. If an alkyl group is attached to the 2-position of the carbon chain of an amide, the amide must be tertiary; however, these *N,N*-dimethyl-2-alkylalkanamides are usually only moderately active. To be highly active, a tertiary amide must not have any substituents attached to the carbon chain; the length of the carbon chain should be between C_{13} and C_{18}. The following partial structures are thus required for the amides to manifest a high level of larvicidal activity.



Since the mode of action of the alkanamides is still unknown, the reason of these structural requirements is not readily understood. Albert (1979) ascribes the influence of methyl groups on biological action to their steric and electronic effects. The steric effects of methyl groups influence the solubility, the covalent hydration, and the chelation of the whole molecules to which the methyl groups are attached. The steric effects also affect whether or not the methylated molecules will fit the receptors or act on the target enzymes. The electronic effects of methyl groups influence the ionization, the redox potentials, and the solubility of the whole molecules and also affect the reactions in which cleavage of a covalent bond takes place. The physicochemical properties of a chemical compound are therefore altered by the presence of methyl groups. As a result, the biological activity of the compounds may change completely. For instance, most molecules that fit the receptor of acetylchloline have a quaternary nitrogen atom of which one substituent is a straight chain of five atoms in length and two of the other substituents must be methyl groups to achieve maximal action. If one of the methyl groups is substituted by either hydrogen or ethyl, a sharp drop in action takes place.

In the present study, a methyl group is required at the 2-position or two methyl groups are required to substitute two hydrogens attached to the amide nitrogen for a higher degree of activity. In view of this structural specificity, it seems reasonable to postulate that the specific partial structures as described above are required to fit the receptors of alkanamides in the insect bodies. Without the presence of the methyl groups, the alkanamides might not fit the receptors and, therefore, fail to exert toxic effect on the insect.

One characteristic feature of the previously reported branched-chain aliphatic carboxylic acids and esters (Hwang et al., 1974a,b, 1976, 1978a) is that they are particularly effective against the younger larvae but do not affect the older larvae to a great extent. Some examples are listed in Table IV. Both 3-methylheptadecanoic acid (**32**) and 3-methyloctadecanoic acid (**33**) exhibited a high degree of larvicidal activity against the first instars whereas their activity greatly diminished against the fourth instars. The methyl esters (**34**, **35**) of these acids were also inactive against the fourth instars in spite of their high degree of activity against the first instars. This selective toxicity was also shown by 3-methyloctadecanamide (**3**), which was active against the first instars but did not show any activity at or below 8 ppm against the fourth instars and the pupae. The 3-methylalkanoic acids and their esters and amides thus demonstrated a similar pattern of selective toxicity that is characteristic of the mosquito autoinhibitors, produced by older larvae of mosquitoes under overpopulated conditions (Hwang and Mulla, 1976b).

N,N-Dimethylalkanamides, on the other hand, displayed a different pattern of activity against the immature mosquitoes. Thus, *N,N*-dimethyldodecanamide (**21**) showed a high level of activity against the first instars, and also considerable activity against the fourth instars, but no activity against the pupae. *N,N*-Dimethyltridecanamide (**22**) and *N,N*-dimethyltetradecanamide (**23**) were highly active against the first instars and surprisingly more active against the fourth instars and the pupae as compared with the acids, esters, and other amides in Table IV. Some *N,N*-dimethyl derivatives of straight-chain alkanamides therefore demonstrated a wide spectrum of insecticidal activity affecting the development of all stages of immature mosquitoes, whereas the branched-chain alkanoic acids, esters, amides had a narrow spectrum of activity affecting only the very young larvae.

Mosquito larvae are susceptible to most organophosphate and carbamate insecticides (Mulla et al., 1966), synthetic pyrethroids (Mulla et al., 1975), and insect growth regulators (Mulla et al., 1974). In general, some commercial and experimental compounds of these groups manifest insecticidal activity in the range of 1–50 ppb against mosquito larvae. Petroleum hydrocarbons and cationic surfactant aliphatic amines are also routinely used for mosquito control; however, the susceptibility of mosquito larvae to these two insecticides is not as great as that to the synthetic insecticides described above (Hagstrum and Mulla, 1968; Micks et al., 1967, 1968; Mulla and Darwazeh, 1971). The effective rates of the petroleum hydrocarbons against mosquito larvae are generally in the order of 20–50 ppm. Even with this low level of activity, the petroleum hydrocarbons are still useful for mosquito control because of their low cost and environmental acceptability. The long-chain aliphatic amines are more effective than the petroleum hydrocarbons, showing excellent control of mosquitoes in the range 1–5 ppm. Some of the alkanamides (e.g., *N,N*-dimethyltetradecanamide) studied here show insecticidal activity in the range 0.2–4 ppm against mosquito larvae and pupae. As compared with the petroleum hydrocarbons and the aliphatic amines, the alkanamides show considerable activity to make them competitive with these control agents. Therefore, our present work on larvicidal and pupacidal alkanamides

seems likely to offer an additional tool for the control of mosquitoes.

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Degradation of 2,3-Dihydro-2,2-dimethyl-7-benzofuranyl (Di-*n*-butylaminosulfenyl)methylcarbamate in Cosad Sandy Loam

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DBSC [FMC-35001 or 2,3-dihydro-2,2-dimethyl-7-benzofuranyl (di-*n*-butylaminosulfenyl)methylcarbamate] was rapidly degraded in Cosad sandy loam with a half-life of about 2–3 days. Thiolysis of DBSC was first order. DBSC degraded to carbofuran, which was either oxidized at the 3 position of the ring or hydrolyzed at the carbamate ester to form carbofuran phenol. Bis(carbofuran)disulfide, dibutylamine, and at least seven unidentified minor compounds were also detected. Phenolic degradation products appeared to be bound to the soil humus by an oxygen-dependent process. Also, ring cleavage was found to be an oxygen-dependent process.

INTRODUCTION

FMC-35001 [2,3-dihydro-2,2-dimethyl-7-benzofuranyl (di-*n*-butylaminosulfenyl)methylcarbamate, hereinafter referred to as DBSC] is a derivative of carbofuran that has excellent insecticidal activity and is substantially less toxic to mammals than carbofuran (Umetsu et al., 1979). The study of the fate of a pesticide and its alteration products in animals, plants, and soil is necessary for the assessment of hazards arising from the use of the pesticide. The fate and metabolism of carbofuran, the precursor of DBSC, have been examined in a variety of biological systems, including soil (Caro et al., 1973; Getzin, 1973; Venkateswarlu, 1977; Williams et al., 1976). Recent reports from this laboratory described the metabolic fate of DBSC in corn and cotton plants and the breakdown of DBSC in an aqueous environment (Umetsu et al., 1979, 1980). This report is concerned with the alteration of DBSC in Cosad sandy loam under aerobic and anaerobic conditions. The degradation of the major primary metabolites, carbofuran and dibutylamine, also was investigated.

MATERIALS AND METHODS

Soil. The Cosad sandy loam used in this research was provided by FMC Corp., Middleport, NY, and was stored at approximately 5 °C. The pH (5.8) of the actual subsample used was measured from a saturated soil paste, and the water-holding capacity (34.4 g of H_2O/100 g of soil) was determined by the Hilgard cup method (Pramer and Schmidt, 1964). The soil contained 3% organic matter. As required, 500–2000 g of soil was removed from storage, partially air-dried at room temperature, worked through a 2-mm sieve, air-dried for 1–2 days, and stored at 14 °C.

Chemicals. [*Carbonyl*-^{14}C]DBSC, and [*ring*-^{14}C]DBSC (specific activities 14.36 and 23.56 mCi/mmol, respectively) were provided by FMC Corp. and purified by column

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