

# Environmental Fate of Esfenvalerate

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This document provides a review of the environmental fate of esfenvalerate, chemical name: (S)- $\alpha$ -cyano-3-phenoxybenzyl-(S)-2-(4-chlorophenyl)-3-methylbutyrate. Esfenvalerate is a mixture of four stereoisomers (Table 1), enriched with the S,S-isomer, the most insecticidally active isomer. The parent mixture, fenvalerate, is a mixture of the same four isomers in relatively equal proportions (Table 1). Thus, this review of esfenvalerate contains data from studies documenting the environmental fate of fenvalerate. The toxicity of the two-isomer mixtures to insects and a variety of non-target organisms has been well documented; however, the environmental chemistry and fate of both mixtures is comparable.

Representative products<sup>1</sup> containing esfenvalerate (registered in California [01/2003]) are: Asana XL (® E.I. duPont de Nemours & Co.), Ever-Sect III Insecticide Concentrate, and Evercide Emulsifiable Concentrate 2668 (® McLaughlin Gormley King), Endure 35WP (® Soil Chemicals Corporation), BugBuster (® Lawn and Garden Products Inc.), Conquer Residual Insecticide Concentrate (® Paragon Professional Pest), Ortho Bug B Gon Multi-Purpose Insect Killer Ready-to-Use (® The Solaris Group), and Total Release Fogger III (® Apollo Industries, Inc.). Currently, there are no Fenvalerate-containing products registered for use in California.

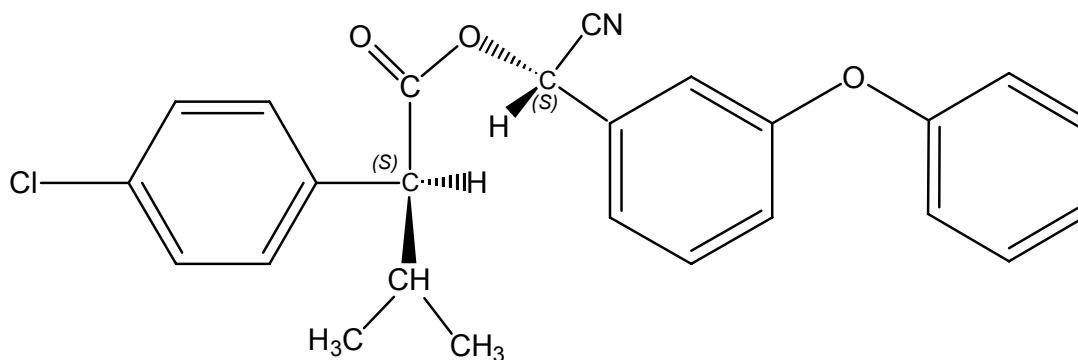
## Overview of Environmental Fate of Esfenvalerate

Esfenvalerate is practically insoluble in water (<2 ppb), extremely hydrophobic ( $\log K_{OW} >6$ ) and has a strong tendency to bind to soil particles ( $K_{OC} = 215,000$ ). Esfenvalerate, as a result of these characteristics, is expected to be relatively immobile in soil and to show a low tendency to leach. Although esfenvalerate has the potential to accumulate in soil, especially following multiple applications in a single growing season, esfenvalerate's potential to pollute ground water, from a non-point source perspective, is expected to be minimal because of its extreme lipophilic nature. Esfenvalerate may contact surface waters either as drift following improper application, or adsorbed to sediment transported to streams following rain events. Esfenvalerate, when present in surface waters, is expected to be bound to suspended particulates (clay, soil, and sediment particles) and to organic matter.

<sup>1</sup> Registered product names are used to provide a representative sample of esfenvalerate-containing pesticide products available for use in California. Inclusion or exclusion of a product does not construe DPR's endorsement or deprecation of any esfenvalerate-containing product.

## Chemical Structure of Esfenvalerate

Figure 1. The Chemical Structure of Esfenvalerate (S,S-Isomer).



(S)- $\alpha$ -cyano-3-phenoxybenzyl-(S)-2-(4-chlorophenyl)-3-methylbutyrate

## Chemical Composition

Fenvalerate and esfenvalerate are pesticidal active ingredients composed of four stereoisomers (Schneiders, 1994). Originally, this mixture was marketed as Pydrin (fenvalerate), a mixture in which all four isomers are relatively equal in concentration (Table 1). However, since the S,S-isomer showed the most insecticidal activity, modern production techniques have been modified to enrich the racemic fenvalerate mixture with the S,S-isomer. The relative isomer composition of fenvalerate (non-enriched mixture) and esfenvalerate (enriched mixture) are shown in Table 1.

Table 1: Relative Isomeric Composition of Pesticide Products Containing Either Fenvalerate (Pydrin) or Esfenvalerate (Asana XL) (Schneiders, 1991)

	Isomer (%)			
	S,S-isomer	R,S-isomer	S,R-isomer	R,R-isomer
Fenvalerate	23	27	27	23
Esfenvalerate	84	8	7	1

## Toxicity of Fenvalerate and Esfenvalerate

The toxicity of fenvalerate and esfenvalerate to a variety of organisms is shown in Table 2. Esfenvalerate shows greater toxicity to honeybees, other invertebrates, and fish species than fenvalerate.

**Table 2. Fenvalerate and Esfenvalerate Toxicity to Non-Target Organisms (CDPR Ecotox Database, 2001)**

Organism	Toxicity Criterion	Toxicity Value	
		Fenvalerate	Esfenvalerate
Rat, Male (oral)	LD <sub>50</sub> (mg/kg)	451	87
Rat, Female (oral)	LD <sub>50</sub> (mg/kg)	ND <sup>†</sup>	67
Rat Reproductive	NOEC <sup>‡</sup> (ppm)	125	<25
Bobwhite Quail	LD <sub>50</sub> (mg/kg)	ND <sup>†</sup>	381
Bobwhite Quail	8-day LC <sub>50</sub> (mg/kg)	10,000	>5,620
Bobwhite Reproductive	NOEC <sup>‡</sup> (ppm)	125	<25
Mallard Duck	8-day LC <sub>50</sub> (ppm)	5,502	5,274
Bluegill Sunfish	96-Hr LC <sub>50</sub> (ppb)	0.64	0.26
Bluegill Sunfish	BCF <sup>§</sup>	ND <sup>†</sup>	3,650x
Rainbow Trout	96-Hr LC <sub>50</sub> (ppb)	6.2	0.26
Sheepshead Minnow	96-Hr LC <sub>50</sub> (ppb)	430	460
Honeybee	LD <sub>50</sub> (µg/bee)	0.408	0.01
<i>Daphnia magna</i>	48-Hr LC <sub>50</sub> (ppb)	1.39	0.24
Mysid Shrimp	96-Hr LC <sub>50</sub> (ppb)	0.038	0.038

<sup>†</sup> ND = No Data

<sup>‡</sup> NOEC = No Observable Effect Concentration

<sup>§</sup> BCF = Bioconcentration Factor

## Physical Properties of Esfenvalerate

The physical and chemical properties of esfenvalerate are presented as Table 3.

**Table 3: Esfenvalerate Physical Properties, Chemical Composition, and Formulation.**

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**Appearance:** Colorless crystals; Technical product is an amber liquid or solid at 23 °C [†].

**Common Name:** Esfenvalerate, (S)-Fenvalerate [‡, #]

**Chemical Name:** (S)- $\alpha$ -cyano-3-phenoxybenzyl(S)-2-(4-chlorophenyl)-3-methylbutyrate [†]

**Synonyms** [†, ‡, §, #, ††, ††]:

(S)-cyano-(3-phenoxy phenyl)-methyl-(S)-4-chloro- $\alpha$ -(1-methyl ethyl) benzene acetate  
Chloro- $\alpha$ -(1-methylethyl)benzeneacetic acid, cyano(3-phenoxyphenyl)methyl ester (CAS)  
(S-(R,R))-4-chloro- $\alpha$ -(1-methylethyl) benzeneacetic acid, cyano-(3-phenoxyphenyl)methylester  
(S)- $\alpha$ -cyano-3-phenoxy benzyl (S)-2-(4-chloro-phenyl) isovalerate  
(S)-fenvalerate  
Fenvalerate A-Alpha  
(S-(R\*,R\*))-Benzenecetic acid, 4-chloro- $\alpha$ -(1-methylethyl)-cyano(3-phenoxyphenyl)methylester  
Cyano-3-phenoxybenzyl (S)-2-(4-chlorophenyl)isovalerate  
Cyano-3-phenoxybenzyl (S)-2-(4-chlorophenyl)-3-methylbutyrate

**Trade Name(s)** [†, ‡, #, ††]:

Sumicidin A-Alpha  
Asana,  
Dupont Asana XL Insecticide  
SS-Pydrin

**CAS Number:** 66230-04-4 [†]

**Formula:** C<sub>25</sub>H<sub>22</sub>ClNO<sub>3</sub> [‡]

**Molecular Weight:** 419.9 [§]

**Melting Point:** 59-60 °C [†]

**Boiling Point:** 151-167 °C (technical formulation) [#]

**Vapor Pressure:** 0.067 mPa @ 25 °C [†]

**Henry's Law Constant:** 1.4 x 10<sup>-7</sup> Pa•m<sup>3</sup>•mol<sup>-1</sup> [††]

**Solubility:**

**Water:** 0.002 mg/L (25° C), [#]

**Organic Solvents:** v.s. in xylene, acetone, chloroform, (>600g/kg at 25 °C) [#]  
s. in hexane (10-50 g/kg) & methanol (70-100 g/kg) at 25 °C [#]

**log K<sub>ow</sub>** 6.2 at 25 °C [###]

**K<sub>oc</sub>** 215,000 [§§]

**Specific Gravity:** 1.26 (4-26 °C) [#]

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†) Kidd, H. and James, D. R., Eds. (1991)

‡) Thompson, W.T. (2001)

§) Wauchope et al. (1996)

#) Royal Society Chemistry (1994)

††) Laskowsk (2002)

†††) DPR (2002a)

§§) E.I. duPont de Nemours (2002)

###) European Commission 2000

## **Mode of Action**

Esfenvalerate is a voltage-dependent sodium-channel agonist (Royal Soc. Chem. 1994). Esfenvalerate works against the insect/arthropod nervous system, resulting in repetitive firing of neurons. When the organism is exposed to esfenvalerate, it may exhibit symptoms of hyperexcitation, tremors, convulsions, followed by lethargy, and paralysis. Following paralysis the insect/arthropod dies (E.I. duPont de Nemours, 2002).

The mode of entry of esfenvalerate into the insect/arthropod is either via contact or through ingestion. Direct contact with spray droplets provides the most effective method of control. A second mode of entry is through consumption of spray droplets or residues present on treated foliage following esfenvalerate application (E.I. duPont de Nemours, 2002)

## **Use**

Esfenvalerate is a broad-spectrum nonselective insecticide applied as needed for the control of a wide selection of arthropod pests. Currently (January, 2003), there are fifty-four esfenvalerate-containing products registered for use in California. These products are applied for the control of pests in three major venues: 1) Consumer use Home/Garden (25 products), 2) Commercial pesticide application (24 products), and 3) Agricultural production (3 products). The remaining two products are technical materials used for formulating end-use products.

### ***Consumer Use Products***

Esfenvalerate is marketed as a consumer-use product, applied in and around the home, on lawns, on fruit trees, and in vegetable gardens for the control of insects (silverfish, cockroaches, termites, earwigs, beetles, moths, fleas, flies, and ants and wasps), spiders, ticks and mites, centipedes scorpions, and other arthropod pests (CDPR, 2002; CDPR, 2002b). Formulations are aqueous and emulsifiable concentrates, pressurized gas, pressurized liquids/sprays/foggers, ready-to-use solution/liquids, and wettable powders (CDPR, 2002).

### ***Commercial Use Products***

Esfenvalerate-containing products are used for the control of cockroaches, silverfish, beetles, flies, fleas, and ant and wasp pests in schools, eating establishments, processing plants, veterinary hospitals, refuse and solid waste sites, and dairy areas (CDPR, 2002a, CDPR, 2002b). Formulations are emulsifiable concentrates, pressurized liquids/sprays/foggers, ready-to-use solution/liquid, and wettable powders (CDPR, 2002a).

***Agricultural Use Products***

Esfenvalerate is especially effective against grasshoppers, bugs, thrips, mosquitoes, flies, beetles, and moth pests in agricultural settings. E.I. duPont de Nemours (2002) suggests that Asana XL be incorporated into an Integrated Pest Management (IPM) System, and that applications be based on IPM principles. Esfenvalerate may be applied at the first sign of pests/pest damage, generally as a Ultra Low Volume spray, and may also be applied via chemigation (injected into irrigation water) (CDPR, 2002a; 2002b). Crop systems to which esfenvalerate may be applied are corn, sugarbeets, fruit and nut crops, tomatoes, and vegetable crops. In 2000, approximately 32,000 lbs of esfenvalerate were applied (Table 4) (CDPR, 2002c). The majority of esfenvalerate applications occur during mid- to late-winter to nut crop/fruit trees as a dormant spray (CDPR, 2002d). Formulations are emulsifiable concentrates, ready-to-use liquids, and wettable powders (CDPR, 2002a).

**Table 4: Amount of Esfenvalerate Applied to Crop Systems in California (2000)**

<b>Commodity</b>	<b>Lbs AI<sup>†</sup></b>
<b>Nut Crops</b>	
Almond	4,250
Walnut	1,450
<b>Stone Fruits</b>	
Peach	2,800
Nectarine	1,375
Other Stone Fruits (cherry, plum, apricot <sup>‡</sup> )	3,800
<b>Vegetables</b>	
Artichoke, Globe	2,135
Beans and Peas	750
Cole Crops	0
Broccoli	1,300
Other Cole Crops (cauliflower, cabbage, Brussels sprouts, etc. <sup>‡</sup> )	850
Corn	2,800
Leafy Vegetables (lettuce, spinach, “greens”)	900
Lettuce, Head	900
Melon/Squash (cantaloupe, watermelon, cucumber, pumpkin, zucchini <sup>‡</sup> )	550
Tomato,	3,700
<b>Pome Fruits</b>	
Pear, Apple	800
<b>Root Crops</b>	
Sugarbeet	1,350
Other Root Crops (potato, carrot, radish <sup>‡</sup> )	1,375
<b>Miscellaneous Use</b>	936
<b>Total pounds applied</b>	<b>32,021</b>

<sup>†</sup> AI = Active Ingredient

<sup>‡</sup> Crops in combined categories are ordered from high to low in pounds esfenvalerate applied.

## Fate of Esfenvalerate in the Environment

Upon original registration of esfenvalerate, there was little environmental fate data for the specific stereoisomer esfenvalerate (Schneiders, 1994; 1991). Instead, in most instances, representative studies documenting the properties and environmental fate of the racemic mixture fenvalerate are used in place of more definitive esfenvalerate studies (Schneiders, 1994). Recently, more detailed studies have been conducted to determine the specific environmental fate of esfenvalerate.

### *Environmental Half-Lives of Esfenvalerate*

The photolytic half-life of esfenvalerate exposed to California winter sunlight on thin layers of wet soil ranged from 14.4 to 17.2 days (Laskowski, 2002). Aerobic degradation of esfenvalerate is more rapid than anaerobic degradation. Aerobic degradation varied according to soil type with half-lives ranging from 35 to 546 days with an average aerobic soil half-life of 51.7 days. Anaerobic degradation of esfenvalerate in soil was slower, the half-life averaged 154 days (range: 104 to 203 days) (Laskowski, 2002).

**Table 5: Environmental Half-Lives of Esfenvalerate.**

<b>Media</b>	<b>Half-life</b>	<b>Reference</b>
Air (DT <sub>50</sub> )	1.2 days	European Commission, 2000
Soil, MM <sup>†</sup> clay (light)	68.3 days	Katagi, 1991
Soil, MM clay (dark <sup>‡</sup> )	553.4	Katagi, 1991
Soil, kaolinite clay	7.8 days	Katagi, 1991
<b><u>Photolysis</u></b>		
Water	17.2 days	Laskowski, 2002
Soil (dry)	10.0 days	Laskowski, 2002
Soil (wet)	15.8 days	Laskowski, 2002
<b><u>Aerobic</u></b>		
Soil	38.6 days	Laskowski, 2002
Water (10 °C)	72.3 days	Laskowski, 2002
Water (15-19 °C)	4.0 days	Lutnicka et al., 1999
<b><u>Anaerobic</u></b>		
Soil	90.4 days	Laskowski, 2002
Water	No data	Laskowski, 2002

<sup>†</sup> Montmorillonite clay

<sup>‡</sup> Soil and esfenvalerate incubated in dark.

### *Fate in Air*

The European Commission, Directorate-General Health & Consumer Protection (2000) reports that the photochemical oxidative degradation of esfenvalerate in air (determined by the Atkinson method) showed a DT<sub>50air</sub> (half-life/50% dissipation time) of 1.2 days. They concluded that esfenvalerate is non-persistent in air.

## ***Fate in Soil***

Degradation of pyrethroids in the soil is mostly by chemical and microbial action. The rate of degradation depends on the pyrethroid, soil type, climate, the species of microbes present, and the size of their populations. In the field, esfenvalerate is expected to tightly bind to soil particles and therefore presents an intermediate (Wauchope et al., 1972) to low (E.I. duPont de Nemours, 2002) potential to move into ground waters or move offsite into surface waters. McBride et al. (1988) reported esfenvalerate to be moderately persistent in a variety of soils, and because of its immobility, to pose little threat to groundwater contamination. Esfenvalerate is practically insoluble in water (<2 ppb), is extremely hydrophobic ( $\log K_{OW} >6$ ) and has a strong tendency to bind to soil particles ( $K_{OC} = 215,000$ ). Esfenvalerate's adsorption to soil is expected to increase as soil organic matter increases. Esfenvalerate and fenvalerate have both been reported to accumulate in soil containing high proportions of organic matter. The National Research Council of Canada (1986) reported that fenvalerate has the potential to accumulate in soil following repeated applications over a single growing season.

Katagi (1991) studied the breakdown and mineralization of esfenvalerate on soil, clay, and humic acid surfaces. Proposed pathways for esfenvalerate breakdown are shown in Figure 2. On montmorillonite, the half-life of esfenvalerate was estimated at 68.3 days in the presence of sunlight and 553.4 days in the absence of sunlight. On kaolinite clay surfaces, the half-life of esfenvalerate was 7.8 days, significantly less than on montmorillonite surfaces. However, on kaolinite surfaces the concentration of esfenvalerate remained relatively stable after 10 days. Accelerated breakdown of esfenvalerate was also noted on Noichi Upland (Japan) soil but Katagi (1991) did not quantify the rate of breakdown.

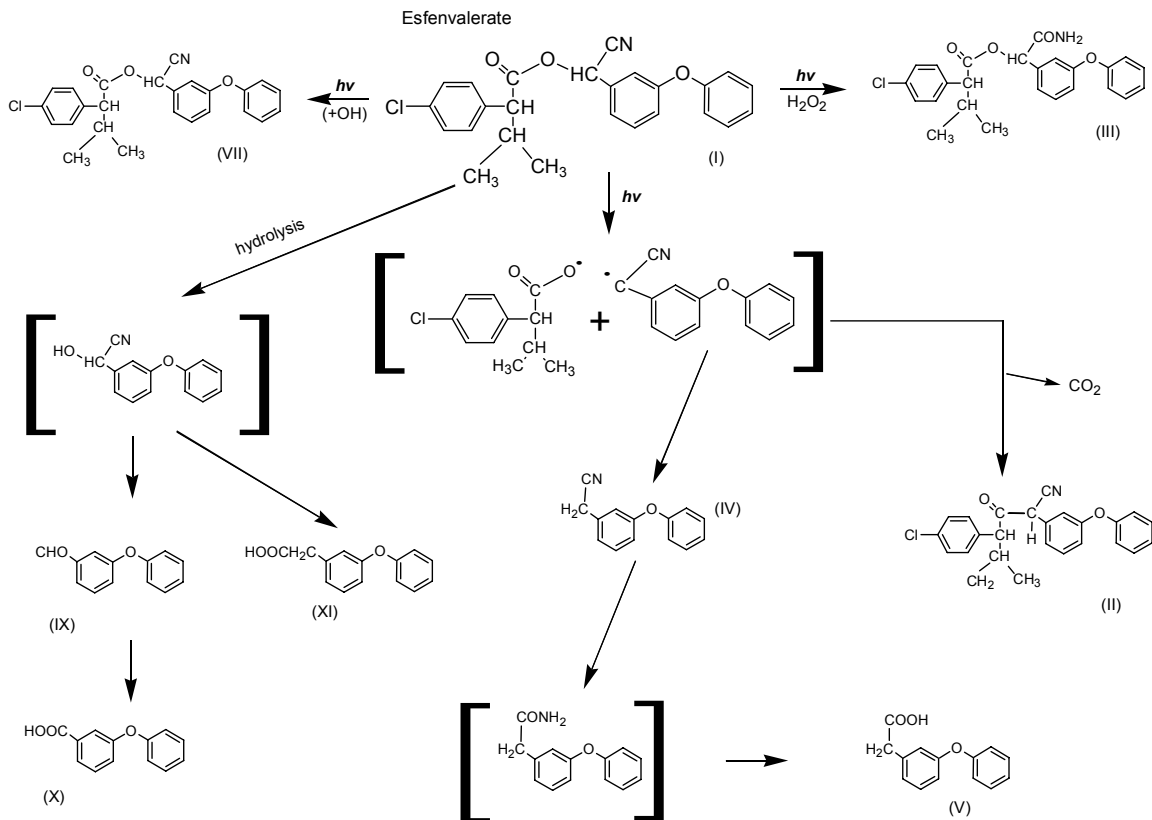
Katagi (1991) also reported that the breakdown of radio-labeled esfenvalerate showed a causative relationship between the amount of volatile and soil surface-bound  $^{14}C$  and irradiation. Breakdown products II, IV, V, VII (Figure 2; Table 6) were found on irradiated soil, clay, and humic acid surfaces at 10 and 21 days, but not on non-irradiated surfaces at 21 days. Photolytic reactions rather than microbial degradation were postulated as the primary mechanism of esfenvalerate breakdown on soil surfaces.

Sakata et al. (1992) showed a differential degradation between the different optical isomers of fenvalerate. Relative rates of breakdown (measured half-life) were greatest for the 2R, $\alpha$ S isomer (17.4 days), followed by the 2S, $\alpha$ S isomer (esfenvalerate) (27.1 days), the 2R, $\alpha$ R isomer (39.5 days), and the 2S, $\alpha$ R isomer (44.5 days).

The European Commission (2000) estimated the  $DT_{50}$  of esfenvalerate from soil dissipation studies to show seasonal and soil-type variations in the United Kingdom.  $DT_{50}$ 's based on actual use conditions ranged from 62 to 126 days following summer applications and 67 to 87 days following autumn applications. Mean values were 70 days in sandy silt loam and 95 days in clay soil after summer applications and 75 days in sandy silt loam and 77 days in clay soils following autumnal applications. These studies are intended to reflect net degradation from all pathways, and the data indicate that esfenvalerate is fairly persistent depending on use conditions and soil type.



**Figure 2: Photodegradation of Esfenvalerate on Soil, Clay Mineral, and Humic Acid Surfaces (after Katagi, 1991; 1994)**



**Table 6: Esfenvalerate Breakdown Products Related to Soil Type (Katagi, 1994; 1991).**

Structure	Soil Type	Reaction/Reactive Site
II	Noichi Upland Soil	Homolytic cleavage of ester moiety
III	Noichi Upland Soil	Decarboxylation via sunlight
IV	Montmorillonite Clay	Hydration of cyano group via sunlight
V	Montmorillonite Clay	Photolysis/hydrolysis of I (Esfenvalerate)
VI	Aqueous Clay Suspension	Hydroxylation
VII	Kaolinite Clay	Cleavage of ester bond
VIII	Kaolinite Clay	Photolysis of I (Esfenvalerate)
IX	Humic Acid Surfaces	Hydrolysis of I (Esfenvalerate)
X	Humic Acid Surfaces	Oxidation of IX
XI	Aqueous Clay Suspension	Photodegradation of III

### *Fate in Aqueous Clay Suspensions*

Katagi (1994) reported that the breakdown of esfenvalerate admixed with clays in aqueous suspensions was similar to the breakdown of esfenvalerate on soil and clay surfaces. Breakdown products remained identical to those in Figure 2 with one new breakdown product detected. Using radio labeled  $^{14}\text{C}$ -esfenvalerate, aqueous clay suspensions were either irradiated or left in darkness. All 9 (II–X) breakdown products as well as a new product (XI) were detected in the irradiated samples (Table 6). Concentrations of breakdown products in irradiated aqueous suspensions were greater than those reported on soil, clay, or humic acid surfaces (Katagi, 1994; 1991). Breakdown products III, VIII, and XI were not detected in non-irradiated aqueous clay suspensions.

### *Fate in Water*

The European Commission, Directorate-General Health & Consumer Protection (2000), reported the photostability ( $\text{DT}_{50}$ ) of esfenvalerate in water is 10 days when exposed to sunlight and 6 days when exposed to artificial sunlight. Hydrolytic stability of esfenvalerate was reported to be 129 days at pH 5 and 65 days at pH 9. Limited hydrolysis was reported at pH 7. Laskowski (2002) reported that esfenvalerate was stable to hydrolysis at three pH values (pH 5, pH 7, pH 9). Lewis (1995) reported a relatively slow rate of degradation of esfenvalerate in aerobic aquatic systems and determined a half-life for aerobic degradation to average 72.3 days (range 65-79 days) in water incubated without light at  $10^\circ\text{C}$  for 100 days. However, Lutnicka et al. (1999) reported fenvalerate to quickly degrade in aqueous solutions, with a half-life of approximately 4 days. Heinis and Knuth (1992) showed that 90% of esfenvalerate was lost from the water column (adsorbed to particulates) within 24 hours following application to littoral enclosures. Volatilization is not expected to play a role in esfenvalerate's disappearance from water due to its very low Henry's law constant.

Laboratory data (Table 1) shows that esfenvalerate is extremely toxic to aquatic organisms. E.I. duPont de Nemours (2002) and Kadlec and Benson (1995) have shown that these toxicity conditions generally do not occur in the field due to esfenvalerate's strong tendency to adsorb to suspended soil, clay, and organic particles in the water column. It is hypothesized that greater toxicity is obtained in the laboratory because 1) Purified water is used in the testing process and 2) A constant concentration of esfenvalerate is maintained throughout the testing regime. It is unlikely that these conditions are actually encountered in the field. Liess et al. (1999) observed that fenvalerate concentrations in agricultural headwaters were event-driven and associated with sediment and suspended mater.

Under natural conditions, contamination of pond water via simulated drift (20% maximum field application rate applied directly to ponds) or runoff (37% maximum field application rate) resulted in no detrimental effects to fish or algae (E.I. duPont de Nemours, 2002). Kadlec and Benson (1995) attributed lower esfenvalerate toxicity to the concentration of natural organic material (NOM) present in natural waters. Lower toxicity was significantly correlated with increasing concentrations of NOM with molecular weight  $> 3700$  Daltons. Detrimental but transient effects were seen on populations of some aquatic invertebrates and long-term effects were noted on sediment-dwelling invertebrates at the highest dose tested (E.I. duPont de Nemours, 2002). Chandler et al. (1994) concluded that fenvalerate toxicity to streambed organisms was due to fenvalerate's association with streambed sediments.

### ***Fate in Plants***

The fate of fenvalerate on and in bean plants is well known, and is shown below (Figure 3). Using  $^{14}\text{C}$ -fenvalerate, Ohkawa et al. (1980) isolated the breakdown products shown in Figure 3. Metabolites were characterized via TLC.

Fenvalerate is transported from foliar surfaces to other parts of bean plants in minute amounts (Ohkawa et al., 1980). Distribution of fenvalerate sixty days following foliar treatment (10  $\mu\text{g}/\text{leaf}$ ) showed that 99.9% of the initially applied fenvalerate remained on and within the leaf itself. Breakdown products identified were the ester metabolites  $\text{CONH}_2$ -fenvalerate and  $\text{COOH}$ -fenvalerate, as well as decarboxyl fenvalerate.

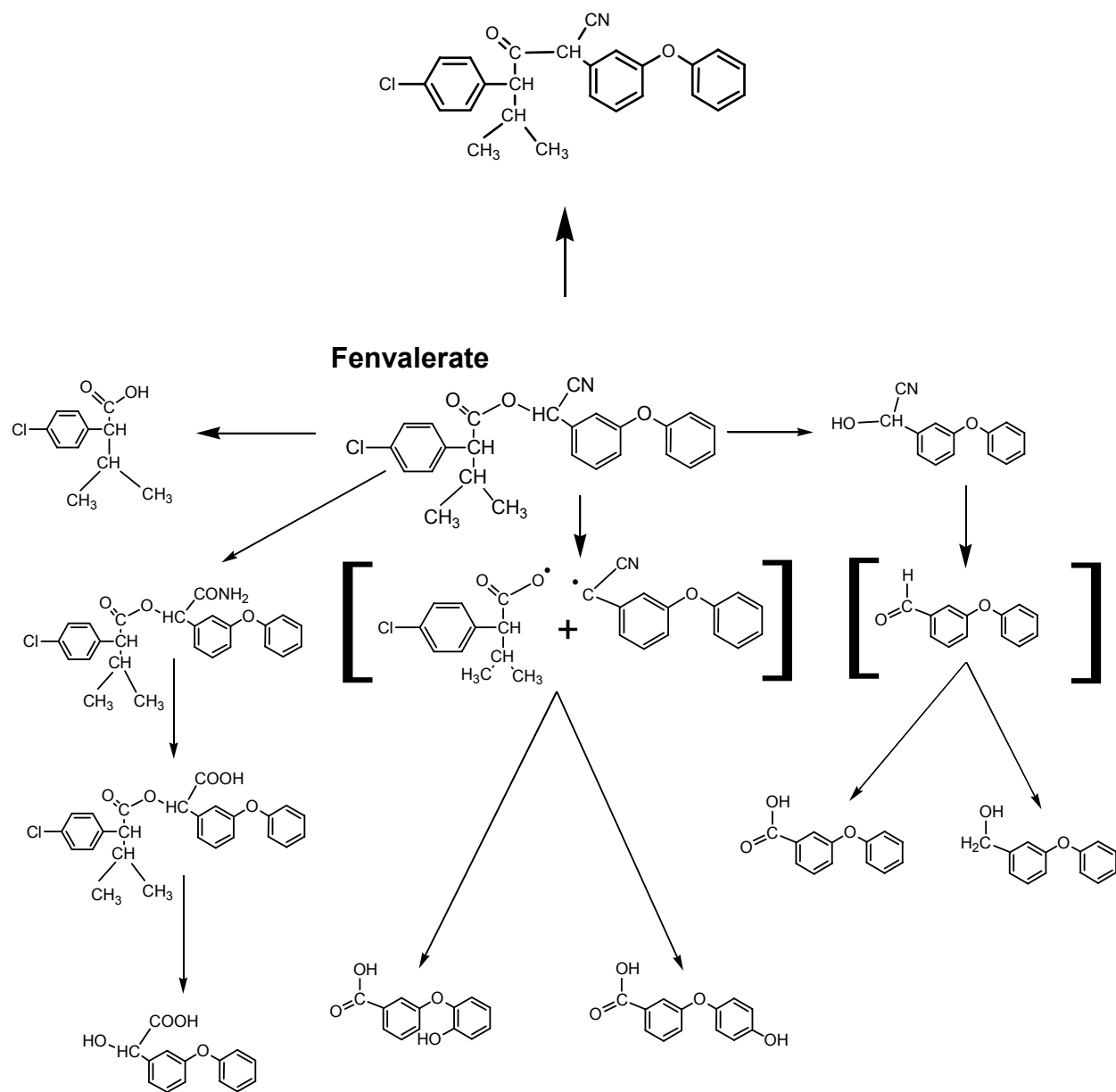
Ohkawa et al. (1980) reported that bean seedlings incubated for 30 days in fenvalerate-containing soil showed very little uptake of  $^{14}\text{C}$ -fenvalerate, and that the main source of  $^{14}\text{C}$ -fenvalerate in/on roots appears to be due to the direct contamination of roots with soil-borne breakdown products. This is related to the fact that fenvalerate appears to be tightly adsorbed to soil particles and limitedly eluted with water.

Das and Mukherjee (1994) showed a significant increase in rice grain and straw production in fields treated with fenvalerate. Increased production was attributed to fenvalerate's stimulation of  $\text{N}_2$ -fixing bacteria and P-solubilizing micro-organisms in treated soil.

### **Conclusion**

Esfenvalerate is broad-spectrum insecticide toxic to most insects, less toxic to birds, and of minimal toxicity to mammals. Esfenvalerate has exceptionally low water solubility, is extremely hydrophobic, and shows a strong tendency to bind to particulates (organic, clay, and soil). Consequently, esfenvalerate has a very limited tendency to leach in soil and a low probability of reaching ground water. Following application, esfenvalerate rapidly associates with particulate matter in soil, and exhibits limited mobility to surface waters. When esfenvalerate contacts surface waters, it rapidly binds to sediment, clay, and dissolved organic matter present in the water column. Although aqueous toxicity under laboratory conditions is high, the adsorption of esfenvalerate to sediments and dissolved organic matter in the environment reduces esfenvalerate's bioavailability and thus its toxicity to aquatic organisms. Bioavailability of particulate-bound esfenvalerate to aquatic and sediment-dwelling organisms remains a subject for further study.

**Figure 3: Fate of Fenvalerate On and In Bean Plants (after Ohkawa et al. 1980)**



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