Radical Oxidation of 3-(4-Chlorophenyl)-1,1-dimethylurea in Aqueous Media

Fred S. Tanaka* and Ronald G. Wien

The oxidation of 3-(4-chlorophenyl)-1,1-dimethylurea (I, monuron) with chemically generated free radicals was investigated to identify oxidation products and to determine product distribution. Saturated aqueous solutions of approximately 200 ppm were oxidized at ambient temperature with Fenton's reagent ($FeSO_4$ + H_2O_2), and the following products were characterized: 3-(4-chlorophenyl)-1-methylurea (II), 4-chlorophenylurea (III), 3-(4-chloro-2-hydroxyphenyl)-1,1-dimethylurea (VI), 3-(4-chloro-2-hydroxyphenyl)-1-methylurea (VII), 1-(4-chloro-2-hydroxyphenyl)urea (VIII), 3-(4-hydroxyphenyl)-1,1-dimethylurea (XI), 4-chloro-4′-hydroxycarbanilide (XII), 4-chloro-2,4′-dihydroxycarbanilide (XIII), and 6-chloro-2-benzoxazolinone (XIV). Measurement of identified products showed demethylated (21%) and ortho hydroxylated (6%) products in greatest abundance. Polar water-soluble material accounted for the largest fraction (28%) of oxidized monuron. A second oxidizing system ($FeSO_4$, ascorbic acid, H_2O_2, and EDTA) was employed because this system more closely resembled biological conditions. The following products were identified: II, 3-(4-chlorophenyl)-1-formyl-1-methylurea (IV), 3-(4-chlorophenyl)-1-formylurea (V), VI, 3-(4-chloro-2-hydroxyphenyl)-1-formyl-1-methylurea (IX), 3-(4-chloro-3-hydroxyphenyl)-1,1-dimethylurea (X), and XI.

Ring hydroxylation and N-dealkylation appear as major pathways for biological detoxification of pesticides, and the metabolic products suggest that detoxification may occur through radical mechanisms. Involvement of free radicals was suggested for some of the biological effects observed with amitrole (3-amino-*s*-triazole). Therefore, Castelfranco and Brown (1963) conducted a study to determine the means of amitrole action based on its behavior toward free radical generating systems. Similar to biological transformations, many photochemical oxidation products appear also to be formed by radical processes. Several identified metabolic products (Swanson and Swanson, 1968; Frear and Swanson, 1974) and identified photolytic products (Crosby and Tang, 1969; Tanaka et al., 1977) from 3-(4-chlorophenyl)-1,1-dimethylurea (monuron, I) studies were identical. Both biological and photochemical products suggest that oxidation was probably occurring by a one-electron process. Therefore, an investigation of monuron degradation with known oxidizing systems that appear to mimic photochemical and biological oxidation reactions was implemented.

Fenton's reagent (ferrous ion and hydrogen peroxide) was selected as the primary chemical system for free radical generation because the mechanism of oxidation has been well established (Walling, 1975). Fenton's reagent was previously employed to study the free radical degradation of amitrole (Plimmer et al., 1967) and to examine the dealkylation of *s*-triazine herbicides (Plimmer et al., 1971). Therefore, Fenton's reagent oxidation, as a model radical reaction, may provide useful information for the elucidation of radical involvement in the biological and photochemical reactions of monuron.

Since Fenton's reagent requires strongly acidic conditions, an oxidizing system composed of ascorbic acid, ferrous ion, ethylenediaminetetraacetic acid (EDTA) and oxygen was also utilized (Udenfriend et al., 1954). This system generally yields products identical with those obtained in vivo, and hydroxylation is directed to electronegative sites on the aromatic ring (Brodie et al., 1954). Hydrogen peroxide may be substituted for oxygen to give the same products, but the rate of reaction is significantly faster. With the ascorbic acid oxidizing system, Balba and Saha (1974) investigated the radical degradation of aminocarb (4-dimethylamino-3-cresyl methylcarbamate). The aminocarb oxidation products were identical with the major biodegradation products characterized from rat liver microsomes, plants, and insects. This oxidizing reagent with its EDTA buffered system appears to more closely resemble physiological conditions than does Fenton's reagent. In this study the ascorbic acid system was employed with hydrogen peroxide as oxidant to accelerate the rate of reaction.

U.S. Department of Agriculture, Science and Education Administration, Federal Research, Metabolism and Radiation Research Laboratory, Fargo, North Dakota 58105.

EXPERIMENTAL SECTION

Materials and Equipment. Unlabeled monuron and [*ring*-^{14}C]monuron (Tanaka, 1970) were prepared in the laboratory. Thin-layer chromatography (TLC), autoradiography, liquid scintillation counting, infrared (IR), and mass spectral equipment and methods were the same as previously described (Tanaka et al., 1977).

Experimental Procedure. Preparative level reactions with Fenton's reagent were performed for the qualitative studies. Saturated aqueous solutions of monuron at approximately 200 ppm were prepared as previously described (Tanaka et al., 1977). Into a 1-L beaker were added 500 mL of saturated aqueous monuron (ca. 0.5 mmol), 6.2 g (22 mmol) of crystalline ferrous sulfate ($FeSO_4 \cdot 7H_2O$), and 2 mL of concentrated sulfuric acid. The mixture was stirred magnetically until a homogeneous solution was obtained. Then 0.5 mL of 30% hydrogen peroxide was very slowly added at varying intervals over an 8-h period. The mixture was allowed to react at approximately 28 °C for 24 h. Products were extracted from the aqueous phase with ethyl acetate and purified for identification with preparative TLC.

For estimation of product yields and for material balance studies, microscale radiochemical experiments were conducted. Into a 25-mL round-bottom flask was added 10 mL of aqueous [*ring*-^{14}C]monuron with a specific activity of 1 mCi/mmol at a concentration of 166 ppm. Crystalline ferrous sulfate (125 mg) and concentrated sulfuric acid (40 μL) were added to the aqueous monuron and allowed to stir into solution. At the beginning of the oxidation reaction, 5 μL of 30% hydrogen peroxide was added, and after 8 h of reaction time, an additional 5 μL of peroxide was added. Reactions were performed in a constant temperature bath at 29 ± 1 °C over a 24-h period. For analysis, 60-μL aliquots of the aqueous reaction mixture were spotted directly onto precoated Anasil HF plates without extraction. The TLC plates were dried with warm air and developed in two dimensions.

Degradation of monuron with the ascorbic acid oxidizing system was accomplished with the following procedure. Saturated aqueous solutions of monuron (500 mL) were treated with 1 g of crystalline ferrous sulfate, 2.5 g of ascorbic acid, and 2 g of tetrasodium ethylenediaminetetraacetic acid. The reactions were allowed to stir in the presence of air for 24 h at approximately 28 °C. The oxidation products were isolated and analyzed in the same manner as with the Fenton's reagent study.

Identification of Oxidation Products. The spectral data given below were used for the characterization of the oxidation products. Compounds I, II, IV, and XI were previously identified in the monuron photochemical study; therefore, their spectral data were reported earlier (Tanaka et al., 1977). Authentic standard of III was provided by E. I. duPont deNemours and Co., standard V was synthesized according to the method reported by Crosby and Tang (1969), and standard VIII was synthesized by R. E. Kadunce from 4-chloro-2-methoxyaniline (Frear and Swanson, 1974). The chemical structures for compounds I–XIV are given in Table I.

III. IR 3430 (NH), 3320 (NH), 1650 (C=O), 1250, 1090, 868, 820, 770, 730 cm^{-1}; mass spectrum m/e (rel intensity) 170 (molecular ion, 18), 153 (3), 127 (100), 44 (13). Spectral results were in agreement with the authentic standard.

V. IR 3370 (NH), 1720 (C=O, formyl), 1690 (C=O), 1260, 1240, 1180, 1096, 1015, 900, 835, 750 cm^{-1}; mass spectrum m/e (rel intensity) 198 (molecular ion, 4), 170 (33), 127 (100). Color reaction with N_2O_3 and *N*-(1-naphthyl)ethylenediamine dihydrochloride gave a positive test for the NHCHO group (Crosby and Tang, 1969). Experimental results were in agreement with the authentic standard.

VII. IR 3380 (OH), 3360 (NH), 3150 (NH), 1670 (C=O), 1280, 1228, 1108, 908, 844, 809 cm^{-1}; mass spectrum m/e (rel intensity) 200 (molecular ion, 8), 169 (15), 143 (100), 113 (10), 78 (22), 58 (33), 44 (6). Color reaction with 2,6-dichloroquinone-4-chloroimide (Gibb's reagent) gave a positive test, indicating either ortho or meta hydroxylation (Feigl, 1966). The moderately intense peak at m/e 169 indicated the hydroxyl group to be located at the ortho position (Still, 1971).

VIII. IR, 3470 (OH), 3340 (NH), 1740 (C=O), 1280 (broad), 1205, 1125, 1086, 906, 868, 814, 748 cm^{-1}; mass spectrum m/e (rel intensity) 186 (molecular ion, 11), 169 (49), 143 (100). Gibb's reagent gave a positive test for ortho or meta hydroxylation. The spectral results were in agreement with the authentic standard.

IX. IR 3320 (OH), 3190 (NH), 1700 (C=O), 1274, 1255, 1227, 1116, 900, 844, 800, 742 cm^{-1}; mass spectrum, m/e (rel intensity) 228 (molecular ion, 34) 169 (100), 143 (14), 113 (22), 78 (37), 58 (37). Test with Gibb's reagent was positive, and the test for NHCHO group was positive (cf. V). The base peak at m/e 169 verified that hydroxyl substitution was located at the ortho position.

X. IR 3380 (NH), 1650 (C=O), 1215, 1060, 868, 858, 808, 745, 686 cm^{-1}; mass spectrum m/e (rel intensity) 214 (molecular ion, 13), 169 (4), 72 (100), 45 (13), 44 (69). Due to limited amount of material, X was only tentatively identified.

XII. IR 3310 (NH), 1645 (C=O), 1232 (broad), 1100 (broad), 1017, 830, 650 cm^{-1}; mass spectrum m/e (rel intensity) 262 (molecular ion 10), 153 (63), 135 (38), 127 (73), 109 (100). Color reaction with Gibb's reagent was negative, suggesting para hydroxylation. A very intense mass spectral peak at m/e 127 showed the presence of a *p*-chloroaniline group and the base peak at m/e 109 showed the presence of a *p*-hydroxyaniline group. The absence of the peak at m/e 169 verified the absence of ortho hydroxylation. Intense peaks at m/e 153 and 135 for the isocyanate fragments indicated unknown XII was cleaved on both sides of the carbonyl group and showed the structure to be a substituted carbanilide.

XIII. IR 3300 (NH), 1600 (C=O, doublet), 1232 (broad), 1120 (broad), 1088, 932, 892, 856, 816 cm^{-1}; mass spectrum m/e (rel intensity) 278 (molecular ion, 2), 169 (62), 143 (85), 135 (75), 109 (100). Color reaction with Gibb's reagent was positive. The intense mass spectral peak at m/e 169 showed one hydroxyl group to be ortho substituted on the aromatic ring containing chlorine. The chlorine isotopic cluster was characteristic for one chlorine atom. The base peak at m/e 109 for *p*-hydroxyaniline verified that the second hydroxyl group was located on the other aromatic ring.

XIV. IR 3420 (OH), 3400 (NH, broad), 1645 (C=O, small) 1100 (very broad), 902, 844, 813, 790 cm^{-1}; mass spectrum m/e (rel intensity) 169 (molecular ion, 54), 143 (2), 125 (14), 113 (21), 78 (34), 44 (100). Gibb's reagent gave a positive result. The mass spectrum gave a base peak at m/e 44 (CO_2), indicating previous ring closure suggesting XIV to be a benzoxazolinone.

DISCUSSION

Free radical generation with Fenton's reagent was accomplished with hydrogen peroxide and ferrous ion which yields ferric ion, hydroxide ion, and hydroxyl radical (eq 1). The hydroxyl radical is the reactive species in Fenton's reagent, and once generated, this species can react with organic molecules in solution by abstraction of hydrogen to yield organic radicals (eq 2). Further oxidation of

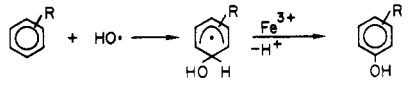
$$H_2O_2 + Fe^{2+} \rightarrow Fe^{3+} + OH^- + HO\cdot \quad (1)$$

$$RH + HO\cdot \rightarrow R\cdot + H_2O \quad (2)$$

organic radicals results in formation of alcohols (eq 3), and

$$R\cdot + Fe^{3+} + H_2O \rightarrow Fe^{2+} + ROH + H^+ \quad (3)$$

$$RCH_2OH + HO\cdot + Fe^{3+} \rightarrow RCHO + H_2O + Fe^{2+} + H^+ \quad (4)$$



(5)

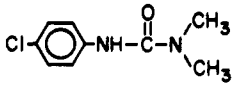
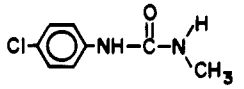
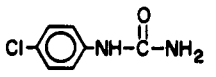
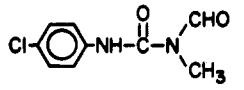
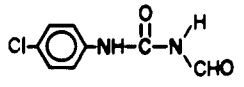
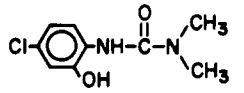
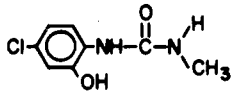
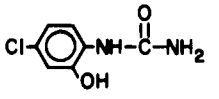
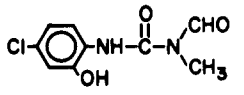
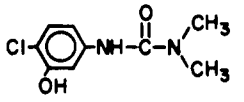
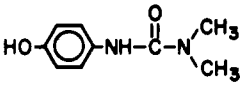
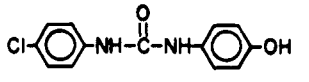
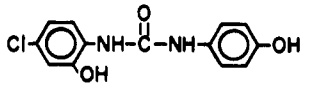
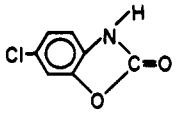
the alcohols in turn may be oxidized to aldehydes (eq 4). For aromatic compounds, the hydroxyl radical adds readily to the aromatic ring to form a radical adduct that upon oxidation with ferric ion yields the ring hydroxylated product (eq 5).

Identified products from monuron oxidation with Fenton's reagent are given in Table I. Based on these products, ring oxidation and N-demethylation appear as important degradation processes. In addition to expected oxidation products, two substituted carbanilides, 4-chloro-4′-hydroxycarbanilide (XII) and 4-chloro-2,4′-dihydroxycarbanilide (XIII), were identified. However, 4,4′-dichlorocarbanilide, an identified photolysis product of monuron, was not detected in this reaction. A heterocyclic 6-chloro-2-benzoxazolinone was tentatively identified, and XIV was apparently present in both keto and enol tautomeric forms:

XIV (6)

Infrared spectroscopy indicated that the enol form was the preferred structure as evidenced by the distinct hydroxyl

Table I. Identified Monuron Degradation Products from Ferrous Ion Oxidation Systems

no.	compound	structure	Fenton's reagent	ascorbic acid reagent
I	3-(4-chlorophenyl)-1,1-dimethylurea		+	+
II	3-(4-chlorophenyl)-1-methylurea		+	+
III	4-chlorophenylurea		+	
IV	3-(4-chlorophenyl)-1-formyl-1-methylurea			+
V	3-(4-chlorophenyl)-1-formylurea			+
VI	3-(4-chloro-2-hydroxyphenyl)-1,1-dimethylurea		+	+
VII	3-(4-chloro-2-hydroxyphenyl)-1-methylurea		+	
VIII	1-(4-chloro-2-hydroxyphenyl)urea		+	
IX	3-(4-chloro-2-hydroxyphenyl)-1-formyl-1-methylurea			+
X	3-(4-chloro-3-hydroxyphenyl)-1,1-dimethylurea			+
XI	3-(4-hydroxyphenyl)-1,1-dimethylurea		+	+
XII	4-chloro-4′-hydroxycarbanilide		+	
XIII	4-chloro-2,4′-dihydroxycarbanilide		+	
XIV	6-chloro-2-benzoxazolinone or 6-chloro-2-benzoxazole		+	

absorption at 3420 cm^{-1} and the weak intensity of the carbonyl absorption band. Thus, the enol form of XIV would be 6-chloro-2-benzoxazole. This benzoxazole might be of interest because the 5-chloro isomer is a skeletal muscle relaxant listed under the trade name, Chlorzoxazone (Merck, 1968).

In Table II are given the product yields derived from monuron oxidation with Fenton's reagent. Yield of unreacted monuron was 23%, and yields of II and III were measured at 18 and 2.6%, respectively. Based on the high yield of II, N-dealkylation appears as a major degradation pathway. The measured yields for VI, VII, and VIII (ortho hydroxylated products) were rather low. Perhaps after initial hydroxylation, these products became labile and were easily oxidized to afford the large quantity of polar water-soluble material. If this were the case, then ring hydroxylation would also be a major pathway for radical degradation of monuron. Product XI was obtained in only

Table II. Product Yields Estimated from Monuron Oxidation with Fenton's Reagent

no.	compound (common name)	% yield
I	monuron	23
II	monomethylmonuron	18
III	*p*-chlorophenylurea	2.6
VI	*o*-hydroxymonuron	2.1
VII	*o*-hydroxymonomethylmonuron	3.0
VIII	*o*-hydroxy-*p*-chlorophenylurea	0.8
XI	*p*-hydroxymonuron analogue	0.5
XII	chlorohydroxycarbanilide	0.1
XIII	chlorodihydroxycarbanilide	0.1
XIV	chlorobenzoxazole	0.1

Table III. Material Balance from Monuron Oxidation with Fenton's Reagent

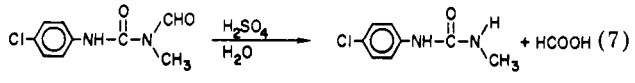
type of material	% original ^{14}C activity
unreacted monuron	23
identified oxidation products	27.3
material remaining on TLC origin	7.3
polar water-soluble material	28
unstable unidentified products	2.5
extraction and work-up losses	3.0
TLC trace products	4.1
TLC losses (unstable volatiles)	4.8
total	100

0.5% yield because para hydroxylation required the concomitant elimination of chlorine from the aromatic ring. Photolytically, this process was more efficient, and the measured yield for XI was the largest of the identified photoproducts (Tanaka et al., 1977). At ground-state energies, however, hydroxyl radical addition with chlorine elimination was of low efficiency. Yields for XII, XIII, and XIV were all very low, and the formation of these products is apparently of only minor importance.

Table III gives the results obtained for the material balance studies conducted with Fenton's reagent. Recovery of unreacted monuron was 23%, and the sum of identified products in Table II accounted for 27.3% of the original radiocarbon. The highly oxidized material remaining on the TLC origin after development (solvents C and A) measured 7.3%. Unidentified polar degradation products in the aqueous phase after extraction were classified as water-soluble material, and these products accounted for 28% of the radiocarbon. Some unstable unidentifiable products were easily separated by TLC, but only decomposed material was obtained after concentration of the pooled fractions. Yield of these unstable products was 2.5%. Extraction and work-up losses were estimated from the difference in total ^{14}C activity of the reaction mixture before and after extraction. This method indicated a 3% loss of radiocarbon during extraction and workup. Spots just detectable by autoradiography and also streaked material along the edges of the TLC plate were classified as trace products. These trace products were responsible for 4.1% of the activity. Finally, 4.8% of the material could not be recovered after TLC analysis. Apparently unstable nonvolatile products were formed in the oxidation reaction, and these products decomposed during chromatography into volatile byproducts which were lost as the TLC plates were dried. This type of material loss was also observed during TLC examination of monuron photolysis products (Tanaka et al., 1977). Therefore, the fate of [^{14}C]monuron after oxidation with Fenton's reagent is summarized in Table III. Apparently, monuron would be completely oxidized to water-soluble products if the reaction were allowed to go to completion.

Products identified from the ascorbic acid–Fe^{2+} oxidation system are also given in Table I. With this system, meta hydroxylated monuron (X) was reported as an oxidation product. Due to the limited amount of material isolated, only mass spectral analysis was accomplished. This product gave the same molecular ion (m/e 214) as a hydroxylated monuron, but the intense peak at m/e 169, a very characteristic ion fragment of ortho hydroxylated analogues of phenylurea and carbanilate compounds (Still and Mansager, 1971; Still, 1971), was not observed. Thus, meta hydroxylation was indicated. In addition, ortho and meta hydroxylated analogues of 4-chlorophenylurea were easily separated by TLC (Ernst and Böhme, 1965; Frear and Swanson, 1974) with the ortho hydroxy compound having a much higher mobility owing to hydrogen bonding between the hydroxyl and carbonyl groups. The mobility of X was observed to be much lower than that of VI (ortho hydroxylated) in solvents C and A during isolation and purification by TLC. Therefore, the chromatographic data further suggested that X was meta hydroxylated. In monuron metabolism studies, Ernst and Böhme (1965) reported the presence of trace quantities of both 4-chloro-2-hydroxyphenylurea and 4-chloro-3-hydroxyphenylurea in rat urine. Hence, meta hydroxylation of monuron metabolites was also demonstrated in biological systems.

In weakly acidic ascorbic acid solution, formation of substituted carbanilides was not observed. Apparently strong acid catalysis is necessary for carbanilide formation, and in agreement with this contention, carbanilide synthesis is usually accomplished with aniline hydrochloride and urea in aqueous solution (Davis and Blanchard, 1961). On the other hand, formyl analogues of monuron were not observed with Fenton's reagent; hence, the hydrolytic stability of the *N*-formyl bond in strong acid was in question. The lability of formyl compounds was tested by placement of IV under the same acidic conditions as in Fenton's reagent. In this experiment, IV was quickly hydrolyzed, and II was the only product detectable by TLC examination (eq 7). Therefore, formyl analogues may be



IV II

intermediates in the oxidative demethylation of monuron with Fenton's reagent; but under the acidic conditions employed, these products were not observed.

Table IV. A Comparison of Different Oxidation Systems

oxidation system	oxidation products: demethylated analogues	methylol analogues	formylmethyl analogues	ortho hydroxylation
cotton plants	yes[a]	yes[c]	no	yes[d]
photochemical	yes[b]	no	yes[b]	yes[b]
Fenton's reagent	yes	no	no	yes
Fe-ascorbic acid	yes	no	yes	yes

[a] Swanson and Swanson, 1968; Frear et al., 1969. [b] Crosby and Tang, 1969; Tanaka et al., 1977. [c] Frear and Swanson, 1972; Tanaka et al., 1972. [d] Frear and Swanson, 1974.

In Table IV are given the different classes of monuron byproducts which exhibit reduced phytotoxicity. On the left side of the table are given the different systems that can effect the transformation of monuron into less toxic materials. The biological system was cotton plants using *Gossypium hirsutum* L., a resistant species (Frear et al., 1969). Photochemical results were taken from studies performed in dilute aqueous solution (Crosby and Tang, 1969; Tanaka et al., 1977).

N-Demethylation was a general reaction observed with all four oxidizing systems. Methylol or hydroxymethyl analogues, however, were observed only with cotton plants, and methylol monuron was isolated as the glucoside conjugate (Frear and Swanson, 1972). Employing monomethyl monuron as substrate, it was possible to isolate and identify the unstable hydroxymethyl analogue (Tanaka, et al., 1972) by derivatization with methanol to afford a stable methoxymethyl derivative. Perhaps methylol intermediates were formed in the initial oxidation reaction of other systems, but owing to the instability of this product, dealkylation or further oxidation would immediately occur to yield either the monomethyl or the formylmethyl analogue of monuron.

Formylmethyl analogues were not observed with cotton plants or with Fenton's reagent. Sulfuric acid concentration in Fenton's reagent was high enough to catalyze the hydrolysis of any formyl analogues that might have been formed during the oxidation process. In the case of cotton plants, further oxidation of methylol to formyl might not be possible because rapid conjugation of the methylol to the glucoside appears to occur, and the methylol may also be rapidly dealkylated due to instability. In either case the methylol intermediate would not be available for further oxidation.

The ortho hydroxylation reaction was observed with all four oxidizing systems. In cotton plants, ortho hydroxylation was observed with 4-chlorophenylurea, a monuron metabolite (Frear and Swanson, 1974), and the glucoside conjugate was again identified. Selective oxidation at the ortho position indicates that these model reactions may prove useful in the investigation of biological ring hydroxylation reaction mechanisms.

This was a preliminary study to determine if similar products could be obtained with radical generating systems in comparison with biological or photochemical systems. Preliminary results already suggest that the demethylation and ortho hydroxylation reactions observed photochemically are due to radical processes. It was also possible, in some instances, to give reasons why products were not observed or why additional products were obtained with the different systems. From the results obtained, it appears that no single process is adequate to act as a model oxidizing system to mimic biological detoxification reactions. However, hopefully by combining the information obtained from several different systems, it may be possible to gain an insight into the mechanisms involved in the biological detoxification reaction of pesticides in plants.

LITERATURE CITED

Balba, M. H.; Saha, J. G. *Bull. Environ. Contam. Toxicol.* **1974**, *11*, 193.
Brodie, B. B.; Axelrod, J.; Shore, P. A.; Undenfriend, S. *J. Biol. Chem.* **1954**, *208*, 741.
Castelfranco, P.; Brown, M. S. *Weeds* **1963**, *11*, 116.
Crosby, D. G.; Tang, C.-S. *J. Agric. Food Chem.* **1969**, *17*, 1041.
Davis, T. L.; Blanchard, K. C. "Organic Synthesis", Coll. Vol. I; Wiley: New York, 1961; pp 453–455.
Ernest, W.; Böhme, C. *Food Cosmet. Toxicol.* **1965**, *3*, 789.
Feigl, F. "Spot Tests in Organic Analysis", 7th ed.; Elsevier: New York, 1966; pp 185, 279.
Frear, D. S.; Swanson, H. R.; Tanaka, F. S. *Phytochemistry* **1969**, *8*, 2157.
Frear, D. S.; Swanson, H. R. *Phytochemistry* **1972**, *11*, 1919.
Frear, D. S.; Swanson, H. R. *Phytochemistry* **1974**, *13*, 357.
Merck & Co., Inc. "The Merck Index", 8th ed; Stecher, P. G., Ed.; Merck: Rahway, NJ, **1968**; p 252.
Plimmer, J. R.; Kearney, P. C.; Kaufman, D. D.; Guardia, F. S. *J. Agric. Food Chem.* **1967**, *15*, 996.
Plimmer, J. R.; Kearney, P. C.; Klingebiel, U. I. *J. Agric. Food Chem.* **1971**, *19*, 572.
Still, G. G.; Mansager, E. R. *J. Chromatogr.* **1971**, *62*, 29.
Still, G. G. *Org. Mass Spectrom.* **1971**, *5*, 977.
Swanson, C. R.; Swanson, H. R. *Weed Sci.* **1968**, *16*, 137.
Tanaka, F. S. *J. Agric. Food Chem.* **1970**, *18*, 213.
Tanaka, F. S.; Swanson, H. R.; Frear, D. S. *Phytochemistry* **1972**, *11*, 2701.
Tanaka, F. S.; Wien, R. G.; Zaylskie, R. G. *J. Agric. Food Chem.* **1977**, *25*, 1068.
Undenfriend, S.; Clark, C. T.; Axelrod, J.; Brodie, B. B. *J. Biol. Chem.* **1954**, *208*, 731.
Walling, C. *Acc. Chem. Res.* **1975**, *8*, 125.

Received for review July 14, 1978. Accepted November 21, 1978. Presented at the 173rd National Meeting of the American Chemical Society, Division of Pesticide Chemistry, New Orleans, LA, Mar 1977. Mention of a trademark, proprietary product, or vendor does not constitute a guarantee or warranty of the product by the U.S. Department of Agriculture and does not imply its approval to the exclusion of other products or vendors that may also be suitable.