Dissipation of Soil-Incorporated Carbofuran in the Field

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In a 2-year investigation, carbofuran dissipation was measured by periodic sampling of soil, runoff, and maize (*Zea mays* L.) crops in two small watersheds to which granular carbofuran had been applied, either broadcast or in the seed furrow. Carbofuran disappeared from soil by apparent first-order kinetics, the half-life ranging from 46 to 117 days. About 5 to 10% converted to 3-ketocarbofuran, which disappeared at about the same rate as the parent. Carbofuran persistence was increased with in-furrow application, more acid soil, and low soil temperature. Pesticide degradation was greatly accelerated in small areas of the watersheds, characterized by high soil water contents, high pH, or heavy soil texture. From 0.5 to 2.0% of the carbofuran applied was lost in runoff, mostly in water rather than in sediments. Less pesticide was lost in a given volume of runoff from an in-furrow application than from a broadcast application. The maize accumulated 0.14% of the applied pesticide by late summer, mostly in the leaves, but residues had decreased sharply by harvest. Most of the pesticide in the leaves had metabolized to 3-hydroxycarbofuran. Carbamate levels in the maize were below established tolerances.

Carbofuran (2,3-dihydro-2,2-dimethyl-7-benzofuranyl-*N*-methylcarbamate) is a highly effective systemic and contact insecticide and nematocide that is used in the Corn Belt for control of the corn rootworm. Although less persistent, carbofuran is more toxic to animals than are most of the organochlorine insecticides. Reported acute oral LD_{50} values for carbofuran are 11 mg/kg in rats, dogs, and chickens (Tobin, 1970) and 1.7 mg/kg in female quail (Sherman and Ross, 1969). By contrast, the value in rats is 100 mg/kg for dieldrin (Snelson, 1966) and 113 mg/kg for DDT (*Chem. Week*, 1969). Consequently, residues of carbofuran and its toxic carbamate products are of concern. The objectives of the 2-year field investigation reported here were (a) to identify the factors influencing the persistence of carbofuran incorporated into the soil in a maize field and subjected to normal agricultural management, and (b) to assess the environmental impact of such treatment by measuring the changes in soil residues with time, the movement of the chemical in runoff water and associated sediments, and the accumulation of the parent compound and its conversion products in the maize plants.

EXPERIMENTAL SECTION

General Description of the Experiments. The field work was conducted at the North Appalachian Experimental Watershed, an Agricultural Research Service station at Coshocton, Ohio. In May of 1971, two small watersheds were treated with granular carbofuran immediately before maize (*Zea mays* L.) was planted. The pesticide was broadcast on one watershed and applied in the furrow along with the maize seed in the other. In May of 1972, carbofuran was applied in the furrow on the watershed that received the broadcast application in 1971; the second watershed was not retreated. In both years, posttreatment samples of soil, runoff water, sediment, and maize plants were analyzed for the content of carbofuran and its two principal conversion products, 3-hydroxycarbofuran (2,3-dihydro-2,2-dimethyl-3-hydroxy-7-benzofuranyl-*N*-methylcarbamate) and 3-ketocarbofuran (2,3-dihydro-2,2-dimethyl-3-oxo-7-benzofuranyl-*N*-methylcarbamate) at the

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Three supporting measurements necessary for interpreting the pesticide data were made. The volume of runoff water from each watershed during and after each posttreatment rainfall was measured automatically at the flumes located at the foot of the sloping watersheds. The amount of sediment carried off the watersheds was measured by collecting a known proportion of the runoff in a 30-gal can located below the flume and connected to it by pipe. The amount of sediment retained in the flumes after each runoff event was estimated by direct field observation.

Watersheds and Treatments. The treated watersheds were fan-shaped, sloping plots which were in a 4-year crop rotation through 1970: a year of maize, a year of wheat, and 2 years of alfalfa–grass meadow. Maize was planted in both fields in both 1971 and 1972. Watershed no. 113, to which carbofuran was applied in both years of the study, consisted of 0.59 ha of Keene (Aquic Hapludalf) and Rayne (Typic Hapludult) silt loam soil, with an average pH of 6.35 and an average slope of 9.3%. Watershed no. 118, receiving carbofuran in the furrow in 1971 only, consisted of 0.79 ha of Coshocton (Aquultic Hapludalf) silt loam, with average pH 5.20 and average slope 9.6%.

To prepare the seedbed, the soils were fertilized, plowed, disked, and harrowed. On May 5, 1971, watershed no. 113 received 31.8 kg (70.0 lb) of 10% active ingredient carbofuran granules (Furadan 10G), equivalent to 5.41 kg/ha (4.83 lb/acre) of carbofuran. The granules were broadcast by continuous feeding from the small-seed box of a 230-cm wide grain drill through tubes to individual spreaders and were disked in to the 7.5-cm depth within 30 min. Maize was planted in rows across the slope 1 hr later. On the same day, watershed no. 118 received 33.0 kg (72.7 lb) of the same granules, equivalent to 4.16 kg/ha (3.71 lb/acre) of active ingredient, applied 5-cm deep in rows 1 m apart, along with the maize seed, with no subsequent cultivation. For the in-furrow treatments, the granules were fed by tube from the pesticide box of a conventional 2-row maize planter through the boot and into the planter shoe. On May 18, 1972, an in-furrow application was made in watershed no. 113, again with 10% active ingredient granules, at a rate of 3.11 kg/ha (2.77 lb/acre) of active carbofuran. Chemical weed control in both watersheds was by preemergence application of triazine herbicides sprayed on the soil surface. In 1971, watersheds no. 113 and 118 received 3.7 and 4.5 kg/ha of atrazine, respectively. In 1972, 2.2 kg/ha of simazine was applied to watershed no. 113.
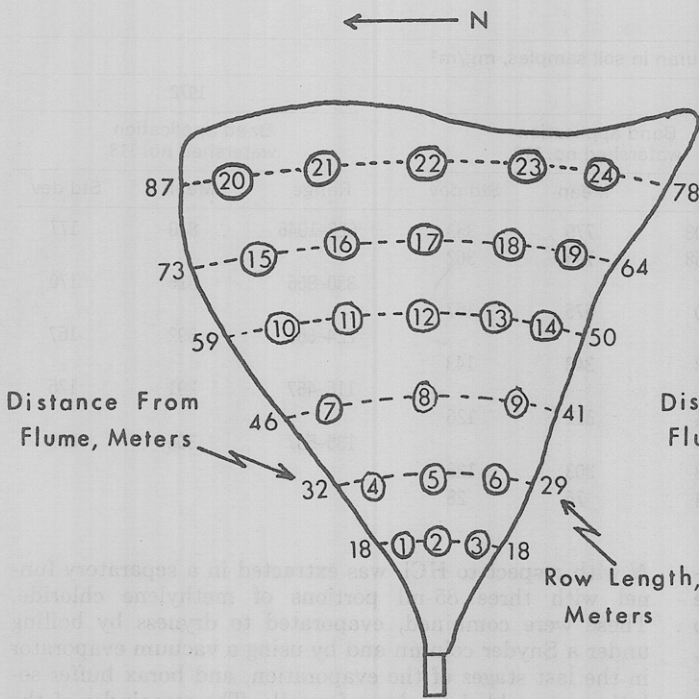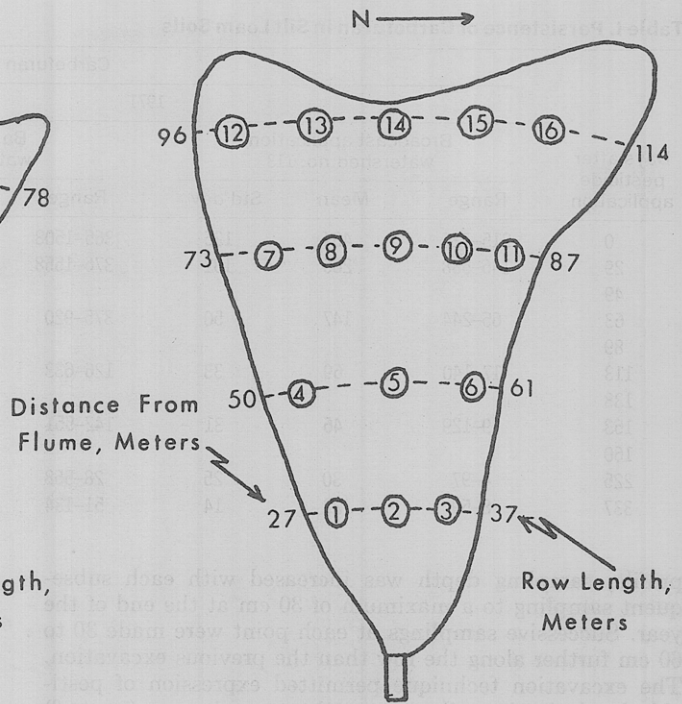
Watershed No. 113
0.587 ha (1.45 acres)

Figure 1. Watershed sampling points in 1971.

Watershed No. 113

Figure 2. Watershed sampling points in 1972.

Figure 3. Sampling the soil.

Sampling Program. Soil samples were taken from each watershed on the day of pesticide application and at 4- to 8-week intervals throughout the remainder of the year. In 1971, 24 sampling points were selected in watershed no. 113, as shown in Figure 1. A similar pattern of 16 sampling points was used in watershed no. 118 (Figure 1). Sampling was less intense on this watershed because it was anticipated that in-furrow application of the pesticide would yield more uniform samples. In 1972, ten sampling points were used in watershed no. 113 in a regular pattern
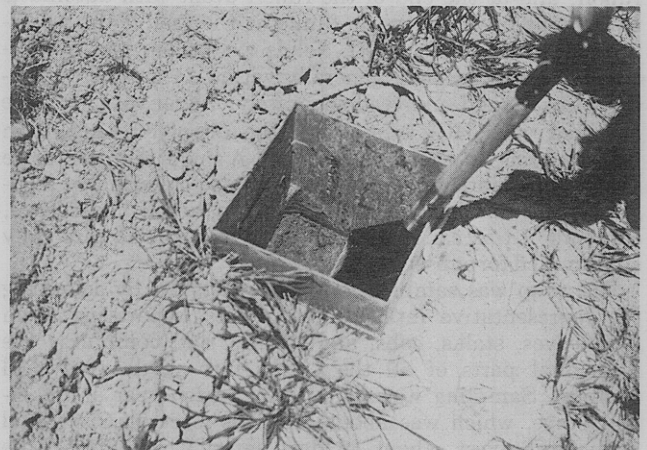
(Figure 2). The reduced sampling intensity was considered sufficient to yield interpretable results in light of the variability among samples that occurred in 1971.

Soils were sampled at each point by driving a square 30 cm × 30 cm steel box, open at both top and bottom, into the soil straddling the maize row to the required depth (Figure 3), excavating the box by shovel, weighing the excavated soil, rolling it on a tarpaulin to reduce within-sample variability, dividing it in a riffle to obtain a 1-l. analytical sample, and returning the unused soil to the original excavation. All these operations were conducted on the watershed. Maize seedlings at the sampling points were removed as they appeared so that plant roots would not interfere with the soil sampling. To ensure complete recovery of the carbofuran in the soil under the area defined by the sampling box, samples were taken to the 10-cm depth on the day of application in 1971 and to the 15-cm depth on the corresponding day in 1972. To compensate for possible leaching of the pesticide in the soil

Table I. Persistence of Carbofuran in Silt Loam Soils

	Carbofuran in soil samples, mg/m²								
	1971						1972		
Days after pesticide application	Broadcast application watershed no. 113			Band application watershed no. 118			Band application watershed no. 113		
	Range	Mean	Std dev	Range	Mean	Std dev	Range	Mean	Std dev
0	215–726	404	126	365–1508	775	353	628–1046	830	177
29	146–588	265	102	376–1558	743	362			
49							330–866	516	170
63	65–244	147	50	375–920	575	157			
89							224–665	392	167
113	17–140	69	33	126–633	343	143			
138							116–467	291	126
153	9–129	46	31	142–551	311	126			
160							135–537	306	159
225	4–97	30	25	28–558	203	126			
337	8–59	22	14	51–134	76	28			

profile, sampling depth was increased with each subsequent sampling to a maximum of 30 cm at the end of the year. Successive samplings at each point were made 30 to 60 cm further along the row than the previous excavation. The excavation technique permitted expression of pesticide levels in the soil on a weight-per-unit-area (mg/m²) basis, rather than on a concentration (ppm) basis. The latter is a less rational, less reproducible quantity in that, if samples are taken to a given depth, it varies with seasonal changes in bulk density of the soil.

In each runoff occurrence, samples of runoff water containing suspended solids were pumped into refrigerated 1-gal jugs at the beginning of runoff, at the time of peak runoff, and at the end of the runoff event with automatic equipment installed in the flume at the foot of the watershed (Harrold et al., 1967). Solids were separated by continuous centrifugation, generally within 24 hr after collection, frozen, and analyzed separately. Water samples were acidified with HCl to stabilize the dissolved carbofuran before storage in a refrigerator at 5°. A single representative sample of sediments and water was also collected in a 30-gal can located below the flume. After runoff had ceased, contents of this can were thoroughly mixed and manually subsampled for subsequent analysis.

The crop was sampled on each watershed by collecting ten representative intact maize plants, separating them into leaves, stalks, cobs, and kernels, and combining the individual parts of all the plants into single analytical samples. Sampling was conducted in each year at the silage stage, which was about 115 days after planting, and again at harvest, about 35 days later. All samples were wrapped in Teflon sheets and frozen for storage until analysis.

Analytical Methods. *Soils and Sediments.* The analytical method used with soils has been described in detail by Caro et al. (1973). Briefly, a 100-g soil sample was digested at 60° for 1 hr with acid ammonium acetate and the extracted pesticide was partitioned into methylene chloride with use of a continuous extractor. The methylene chloride was removed by boiling and vacuum evaporation, and the residual acetic acid was neutralized with sodium bicarbonate. The solution was next buffered with borax and the dinitrophenyl ether derivative of the carbamate pesticide was formed by adding 1-fluoro-2,4-dinitrobenzene and digesting the mixture. The derivative was partitioned into benzene and quantitated by electron-capture gas chromatography. The same basic method was used with sediments. With this method, carbofuran recovered from soils fortified with either solutions or granules of the pesticide exceeded 90% of that applied. No correction for recovery was made in the reported results.

Waters. The water sample, 200 ml previously made 0.25

N with respect to HCl, was extracted in a separatory funnel with three 85-ml portions of methylene chloride. These were combined, evaporated to dryness by boiling under a Snyder column and by using a vacuum evaporator in the last stages of the evaporation, and borax buffer solution was added as above for soils. The remainder of the procedure was the same as for soils. Fortified water samples subjected to this method gave quantitative recovery of carbofuran.

Plant Material. Details of the method for plant analysis have been presented by Turner and Caro (1973). Carbofuran and metabolites were extracted from chopped plant material by refluxing with 0.25 *N* HCl. The extracted pesticides were partitioned into methylene chloride by shaking with three portions of the solvent, which were then combined and concentrated. To remove the oils, kernel extracts were partitioned with acetonitrile and hexane before concentration of the methylene chloride. For final cleanup, all concentrates were subjected to alumina column chromatography. The eluates from the column were evaporated to dryness, treated with borax and fluorodinitrobenzene, and analyzed as above for soils. Fortified plant material gave 93 to 100% recovery of carbofuran, 3-keto-, and 3-hydroxycarbofuran.

RESULTS

Carbofuran persistence in the soil after each of the three treatments is shown in Table I. When graphed, the disappearance curve in each case approximated a first-order reaction during the crop season. In 1971, half-lives calculated by the method of least squares were 46 and 117 days in the broadcast and in-furrow applications, respectively. In 1972, the in-furrow application half-life was 94 days. Disappearance was generally slower during the cold months of the year.

The tabulated standard deviations show that variability in carbofuran content among samples taken concurrently from a given watershed was quite high, despite the use of a soil sampling technique designed to minimize such variation. The irregularities paralleled those found in similar earlier experiments conducted with the organochlorine insecticide, dieldrin (Taylor et al., 1971), and are believed to be largely due to nonuniformity in pesticide application. Substantial reduction in variability cannot be achieved within practical sampling rates (Taylor et al., 1971).

The carbofuran disappeared much faster from a certain small area in each of the in-furrow application watersheds than in the remainder of the treated areas. These "rapid disappearance" areas were defined by sampling points 2 and 5 in watershed no. 118 (Figure 1) and by points 5, 8, and 9 in watershed no. 113 (Figure 2). The residue values
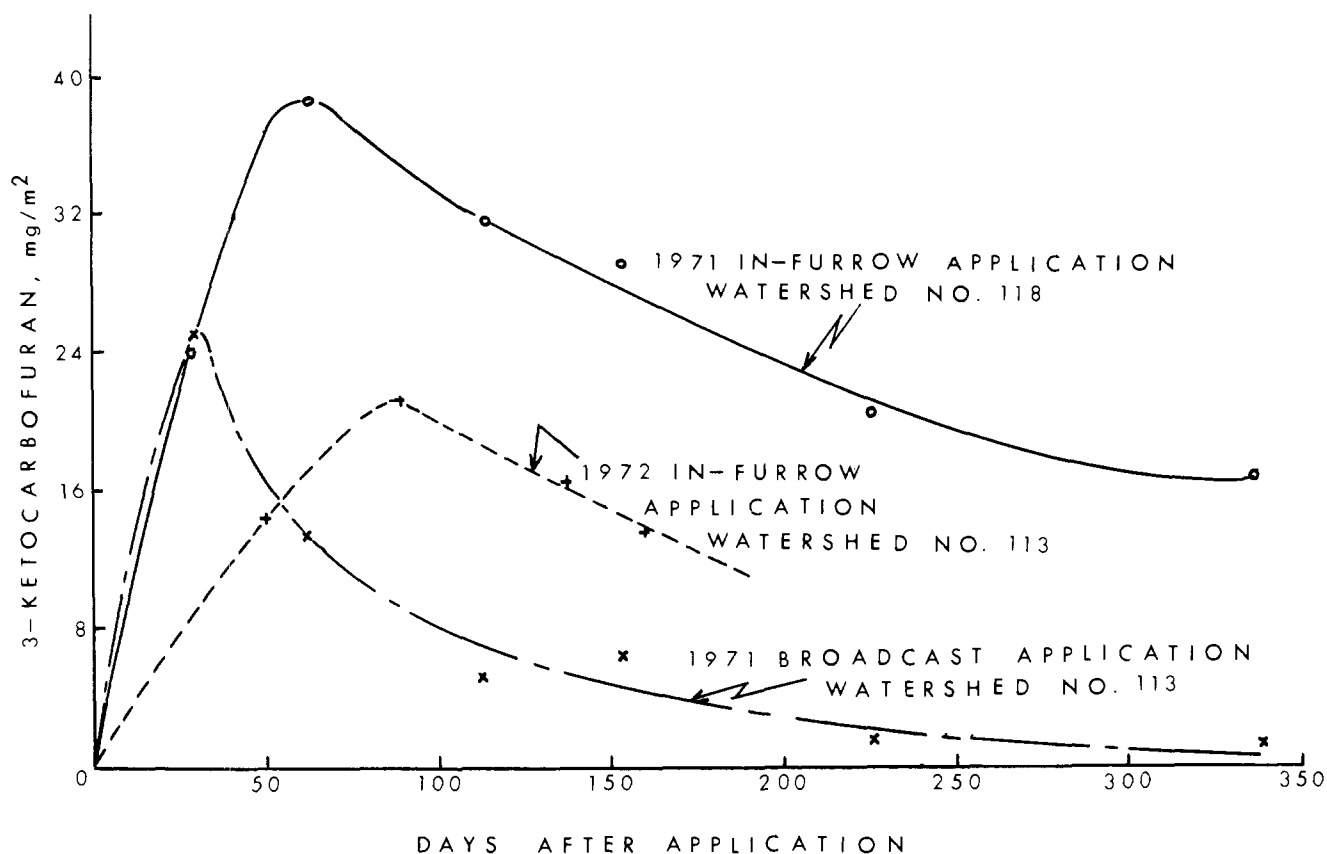
Figure 4. 3-Ketocarbofuran formation and persistence in silt loam soils.

at these points are not included in the data of Table I because an unusual cause of pesticide loss was obviously present that did not occur elsewhere on the watershed. Carbofuran disappearance at the three points in watershed no. 113 corresponded closely to a first-order reaction with 33.5-day half-life. Analyses of soil taken from the areas between maize rows at these sites showed that the pesticide did not move downhill from the treated rows, but did in fact dissipate rapidly at the application sites.

After application of carbofuran to the soil, partial conversion of the pesticide to the oxidation product 3-ketocarbofuran occurred (Figure 4). The product accumulated until a concentration level equivalent to 5 to 10% of that of the carbofuran present was reached and then disappeared at a net rate close to the disappearance rate of the parent compound. Buildup of the product in the broadcast watershed was relatively rapid, with maximum observed concentration at the first sampling, 29 days after application. In both in-furrow application watersheds, by contrast, the buildup did not peak until 60 to 80 days after application. Only sporadic traces of the hydrolysis product 3-hydroxycarbofuran, which is the principal carbofuran metabolite in plant material, were found in the soil samples.

Losses of carbofuran in the runoff water from both treated watersheds in 1971 are shown in Table II. The losses occurred almost entirely in two heavy rains that fell within 48 hr after pesticide application. In both watersheds, carbofuran concentration in the runoff water was much higher in the second rainfall than in the first, suggesting that the applied granules had essentially dissolved by the second day. In 1972, rainfall was more evenly spread over the season, with measurable runoff occurring on the treated watershed on 13 occasions (Table III). Once again, the principal pesticide losses occurred in the early events. The first rain did not take place until almost a month after pesticide application, so that the carbofuran concentrations in the runoff did not reach the high

Table II. Runoff-Producing Rainfalls and Carbofuran Losses in the Runoff Water from Treated Watersheds in 1971

Days after pesticide application	Amount of runoff, l.	Average carbofuran concentration, $\mu g/l$.	Carbofuran in runoff water, mg
Watershed no. 113 (broadcast application)			
1	31900	473	15089
2	7170	1394	9995
39	1480	537	795
65	120	33	4
82	300	15	5
239	3760	5	19
Total	44730		25907
Watershed no. 118 (band application)			
1	40640	272	11054
2	3470	1002	3477
239	9190	19	175
Total	53300		14706

levels of the previous year. The sudden increase in concentration that appeared in events occurring 168 days and later after application was a result of the disturbance of the soil surface at corn harvest, which took place 154 days after the pesticide was applied. 3-Ketocarbofuran in the runoff waters amounted to about 5% of the parent compound, which corresponded to the proportion existing in the soil, but peak concentrations were reached earlier than in the soil (Figure 4).

Some of the rainfall events on the treated watersheds were sufficiently intense to produce measurable quantities of pesticide-bearing soil in the runoff. In 1971, only the two rains that fell within 48 hr after pesticide application did so (Table IV), whereas in 1972, sediments were produced in 8 of the 13 events (Table V). Carbofuran concen-

Table III. Runoff-Producing Rainfalls and Pesticide Losses in the Runoff Water from Carbofuran-Treated Watershed No. 113 in 1972

Days after pesticide application	Amount of runoff, l.	Avg carbofuran concentration, µg/l.	Carbofuran in runoff water, mg	Avg 3-keto-carbofuran concentration, µg/l.	3-Keto-carbofuran in runoff water, mg
26	35840	191	6845	6.9	247.3
28	61320	223	13674	7.4	453.8
53	30710	58	1781	9.3	285.6
76	630	8.8	6	2.3	1.4
82	3190	6.9	22	2.0	6.4
91 (AM)	12430	4.4	55	1.6	19.9
91 (PM)	9170	2.9	27	1.2	11.0
119	1130	2.8	3	1.3	1.5
123	6160	1.8	11	1.7	10.5
147	2710	2.6	7	2.7	7.3
168	11400	14.2	162	1.2	13.7
173	33970	16.9	574	0.7	23.8
179	34020	19.9	677	0.6	20.4
Total	242680		23934		1102.6

Table IV. Carbofuran in Solids in Runoff from Treated Watersheds in 1971

Days after pesticide application	Suspended solids[a]			Flume floor deposit[b]		
	Weight, kg	Carbofuran concentration, mg/kg	Carbofuran content, mg	Weight, kg	Carbofuran concentration, mg/kg	Carbofuran content, mg
Watershed no. 113 (broadcast application)						
1	1732	0.68	1178	618	0.98	606
2	39	1.64	64	0.1	1.03	
Total	1771		1242	618		606
Watershed no. 118 (band application)						
1	600	0.46	275	528	1.11	586

[a] Solid material suspended in the runoff water. [b] Material deposited on floor of watershed discharge flume.

trations were generally higher in the sediment deposited on the flume floor, which was coarser and hence of lower surface area, than in the fine material suspended in the water. This result is the reverse of that from similar field experiments with dieldrin (Caro and Taylor, 1971) and is probably related to the rapid desorption of carbofuran from particle surfaces in contrast to the slower displacement of residues occurring in the interiors of larger particles. Concentrations of 3-ketocarbofuran, determined only in 1972, were near trace levels in the runoff solids, with losses totaling only 1 to 2% of those of the parent materials.

The uptake and distribution of carbofuran and its metabolites in the maize plants in the 1971 experiments have been reported by Turner and Caro (1973). The 1972 data are shown along with the 1971 results in Table VI. Applied carbofuran levels in the vicinity of the plant roots corresponded to 540, 1385, and 1035 mg/m² in watersheds no. 113 (1971), 118 (1971), and 113 (1972), respectively, and the total carbamate residues in the plants reflected the differences in these levels. In all treatments, the plants at harvest contained substantially lower pesticide residues than at the silage stage; in 1972, in fact, no residues were found in the ears at harvest. Residues were concentrated in the leaves, where over 90% of the parent carbofuran was found as the metabolic product 3-hydroxy-carbofuran. In the stalks, only small proportions of the carbofuran had metabolized at the silage stage, whereas at harvest most of the parent material had converted to 3-hydroxycarbofuran. Little metabolism was evident in the cobs at any time.

DISCUSSION

In field experiments designed to answer environmental problems, elaborate plot comparisons and replications are not feasible. It is therefore difficult to identify the precise influence of the individual factors, such as soil pH, soil temperature, and placement (in-furrow vs. broadcast application), that can influence pesticide persistence. However, where supporting data are available from laboratory studies, some useful interpretations of the field results can be made.

In the present experiments, the treatments on the two watersheds in 1971 differed in placement and soil pH, whereas the treatments in 1971 and 1972 on watershed no. 113 differed in placement and soil temperature. The tem-

perature effect may be estimated from the relationship

$$k = Ae^{-E^*/RT} \qquad (1)$$

in which k, the hydrolysis constant, is shown to be an exponential function of E^*, the activation energy, and T, the temperature (Castellan, 1964). The activation energy for carbofuran hydrolysis, as determined experimentally in solution, was 38.5 kcal/mol and the mean soil temperatures over the crop season in watershed no. 113 were 19.8° in 1971 and 18.7° in 1972. Solution of eq 1 with these values shows that the half-life of carbofuran should have been about half longer in 1972 than in 1971. However, the observed half-life was more than twice as long (94 vs. 46 days), suggesting that management practice (placement) is an important variable governing persistence of the pesticide, with a substantial increase in persistence occurring as a result of in-furrow application.

Looking now at the two watersheds treated in 1971, in which carbofuran half-life was measured as 46 and 117 days for the broadcast and in-furrow applications, respectively, the two fields had soil pH values of 6.35 and 5.20, respectively. The half-life of the pure chemical at these two pH levels was measured in solution as 140 and 1600 days, respectively. Thus, it is apparent that the decomposition of carbofuran is activated in soil, but it is not known whether the mechanism of this activation is chemical or biological. The observed difference in insecticide half-life in the two fields was a result of differences in both soil pH and management practice, and the data suggest that both exert a pronounced effect on the persistence of the pesticide.

The "rapid disappearance" areas in the band treatment plots are of interest because their presence illustrates the fact that local conditions can occur within small areas of a field to radically alter the persistence of an applied pesticide. The principal factor causing the decreased persistence is not known, but moisture regime, soil reaction, and physical structure of the soil were likely involved. On watershed no. 118, the two sampling points in question were located directly above the discharge flume in the area of greatest runoff intensity; on watershed no. 113, the "rapid disappearance" area was characterized by a generally higher soil pH level, approximately 0.4 pH unit above that of the remainder of the watershed, and by a more clayey soil texture. In both fields, the soil moisture content was consistently higher in these areas, by approximately 1.2% wet weight basis, on each of the sampling days. No other differences between these sampling points and the rest of the watersheds were evident.

The losses of carbofuran in the runoff in these experiments are summarized in Table VII from the detailed data in Tables II-V. Unlike the behavior of organochlorine insecticides (Caro and Taylor, 1971), most of the carbofu-

Table V. Carbofuran and 3-Ketocarbofuran in Runoff Solids from Carbofuran-Treated Watershed No. 113 in 1972

Days after pesticide application	Suspended solids					Flume floor deposit				
	Weight, kg	Carbofuran		3-Ketocarbofuran		Weight, kg	Carbofuran		3-Ketocarbofuran	
		Concentration, mg/kg	Content, mg	Concentration, mg/kg	Content, mg		Concentration, mg/kg	Content, mg	Concentration, mg/kg	Content, mg
26	2039	0.53	1081.0	<0.01		850	1.76	1496	0.03	25.5
28	5356	1.09	5838.0	0.01	53.6	773	1.76	1361	0.03	23.2
53	377	0.17	64.1	0.03	11.3	568	0.24	136.3	0.03	17.0
91 (AM)	52	0.07	3.6	0.01	0.5	7	0.26	1.8	0.01	0.1
91 (PM)	84	0.05	4.2	0.02	1.7	14	0.31	4.3	0.02	0.3
119	25	0.08	2.0	0.03	0.8					
123	510	0.08	40.8	0.01	5.1	5	0.07	0.4	0.01	0.1
147	37	0.04	1.5	0.04	1.5	5	0.08	0.4	<0.01	
Total	8480		7035		74.5	2222		3000		66.2

Table VI. Carbamate Insecticide Residues in Maize Plants Grown on Carbofuran-Treated Watersheds in 1971 and 1972

Insecticide	Insecticide content, ppm dry weight											
	Leaves			Stalks			Cobs			Kernels		
	I[a]	II	III	I	II	III	I	II	III	I	II	III
	Silage stage											
Carbofuran	0.43	1.07	0.78	0.24	1.10	0.32	0.04	0.37	0.02	0	<0.01	0
3-Hydroxycarbofuran	4.67	9.88	9.31	0.04	0.18	0.18	<0.02	0.04	<0.02	0	0	<0.01
3-Ketocarbofuran	0.40	0.77	0.76	0	0	<0.01	<0.02	<0.02	0	<0.01	<0.01	0
Total carbamates	5.50	11.72	10.85	0.28	1.28	0.50	0.05	0.42	0.02	<0.01	<0.01	<0.01
	Harvest stage											
Carbofuran	0.21	0.19	0.12	0.03	0.10	<0.01	0.06	0.07	0	<0.01	0	0
3-Hydroxycarbofuran	1.51	3.00	1.70	0.05	0.29	0.15	0	<0.01	0	0	0	0
3-Ketocarbofuran	0.34	0.48	1.04	0	0	<0.01	0	0	0	<0.01	0	0
Total carbamates	2.06	3.67	2.86	0.08	0.39	0.16	0.06	0.07	0	0.01	0	0

[a] I, watershed no. 113, 1971, broadcast application; II, watershed no. 118, 1971, band application; III, watershed no. 113, 1972, band application.

Table VII. Summary of Carbofuran Losses in Runoff

Watershed no.	Year	Kiloliters of runoff	Carbofuran applied, g	Loss of carbofuran, g, in			
				Water	Suspended solids	Flume deposit	Total loss, g
113	1971	44.7	3180	25.9	1.2	0.6	27.7
118	1971	53.3	3300	14.7	0.3	0.6	15.6
113	1972	242.7	1820	25.0[a]	7.1[a]	3.1[a]	35.2

[a] Includes 3-ketocarbofuran, 1-4% of total.

ran moved in the water rather than in the associated solids, a reflection of its much higher aqueous solubility. Another consequence of the high solubility was the relatively high proportionate loss of the insecticide in the runoff, which ranged from 0.5% (watershed no. 118) to 2.0% (watershed no. 113, 1972) of the total applied to the field. The data show that, for a given volume of runoff, losses from an in-furrow application of the pesticide would be less than when the material was broadcast, again accentuating the importance of management practice in controlling the environmental impact of pesticide use.

Calculations of the quantities of carbamates accumulated in the maize plants in the 1972 watershed by integration of the individual concentrations (Table VI) showed that the crop contained the equivalent of 0.14% of the applied carbofuran at the silage stage and 0.04% at harvest. This uptake was five times greater than that observed earlier with dieldrin (Caro and Taylor, 1971), but this was to be expected since carbofuran is known to be translocated through plant roots and to act as a systemic insecticide, whereas dieldrin accumulates in plants chiefly by low-level volatilization from the soil surface and recondensation on plant surfaces. It is worth noting that carbamate residue levels in the maize were below established

tolerances (Federal Register, 1972) despite the use of relatively high application rates.

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