

some M-4. Thus, M-5 produced as an intermediate in the metabolism of I would be mostly excreted. On the other hand, it is expected that M-4 will be readily metabolized to further degradation products.

On the basis of the above results and discussion, some of the possible metabolic pathways of I are summarized in Figure 8. The results of further studies on the formation of mercapturate and on the unidentified products present in the acidic fraction will be reported elsewhere.

Registry No. I, 126-73-8; II, 89197-69-3; III, 89197-70-6; IV, 89197-71-7; Va, 107-66-4; Vb, 7242-59-3; VI, 4134-56-9; VII, 19216-62-7; VIII, 819-43-2; IX, 1498-52-8; X, 10463-06-6; XI, 89197-72-8; XII, 52551-81-2; XIII, 89197-73-9; XIV, 89197-74-0; XV, 89197-75-1; XVI, 89197-76-2; XVII, 89197-77-3; XVIII, 89197-78-4; XIX, 89197-79-5; M-4, 1623-15-0; M-5, 107-66-4; M-6, 89197-80-8; M-7, 89197-81-9; M-8, 89197-82-0; M-9, 89197-83-1; M-10, 89197-84-2; M-11, 89197-85-3; 1,3-butanediol, 107-88-0; 1,4-butanediol, 110-63-4; 1,2-butanediol, 584-03-2.

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Effects of Light Intensity and Temperature on the Uptake and Metabolism of Soil-Applied [¹⁴C]Phorate by Plants

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The potential effects of light intensity [500 or 3000 foot-candles (ft-c)], temperature (13 or 28 °C), and combinations thereof were investigated relative the fate of [¹⁴C]phorate in soils and its uptake and metabolism by oat, pea, and corn plants. Increasing the intensity of light, particularly at a temperature of 28 °C, resulted in decreased recoveries of phorate from soils and an increased translocation of ¹⁴C compounds into plant tops. Increasing the temperature from 13 to 28 °C, particularly at the greater light intensity of 3000 ft-c, resulted in an accumulation of ¹⁴C compounds in plant tops but also in an accelerated metabolism of the insecticide. This was indicated by increased production of water-soluble and bound ¹⁴C compounds and an increased formation of ¹⁴CO₂ from ¹⁴C compounds. At a temperature of 28 °C and a light intensity of 3000 ft-c the amounts of phorate and its metabolites in soils had decreased, while in plant tops the amounts of some phorate metabolites such as phorate sulfoxide, phoratoxon sulfoxide, and phoratoxon sulfone had increased.

Many interrelated factors such as temperature, light intensity, photoperiod, air humidity, air movement, plant characteristics, and others can affect the uptake and metabolism of soil-applied insecticides by plants, thus necessitating a knowledge of the effects and interrelation of each of these factors. HacsKaylo et al. (1961) reported that temperature was more important than relative humidity in its effects on the accumulation of soil-applied phorate by cotton plants, while Wheeler et al. (1967) did not observe differences in the quantities of dieldrin taken up by rye grown at 18 °C or at 24 °C for 21-24 days. Tietz (1954) found that *Coleus* plants exposed to 60% relative humidity (RH) in a closed system translocated larger quantities of demeton to the leaves and also released more volatile ¹⁴C than plants exposed to 70% RH.

A study conducted previously in our laboratory dealt with differences in water transpiration by a number of C₃

and C₄ plants in relation to the uptake and metabolism of soil-applied [¹⁴C]phorate (Anderegg and Lichtenstein, 1981). This present study was conducted in the Biotron of the University of Wisconsin to investigate potential effects of different combinations of light intensity and temperature on the fate of the insecticide phorate in soils and its uptake and metabolism by oat, pea, and corn plants.

MATERIALS AND METHODS

Chemicals. [*methylene*-¹⁴C]Phorate (specific activity 9.7 mCi/mmol) was obtained through the courtesy of American Cyanamid Co. The insecticide was determined to be at least 97% pure by thin-layer chromatography (TLC) and autoradiography. The [¹⁴C]phorate was diluted with nonradioactive phorate before its addition to soils. Phorate sulfoxide, phorate sulfone, phoratoxon, phoratoxon sulfoxide, and phoratoxon sulfone were also supplied by American Cyanamid Co. Solvents used were redistilled acetone, benzene, and hexane, as well as analytical-grade methanol, toluene, nitromethane, and acetonitrile.

Plant Material. Corn seeds (hybrid variety Funk G4444-0900, wilt resistant) were obtained through the

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courtesy of Funk Seeds International, Bloomington, IL. Oats (Lodi) and peas (Alaska, wilt resistant) were purchased from a local seed dealer. These seeds had not been pretreated with insecticide or fungicide.

Soil Treatment. A Plainfield sand (0.6% organic matter, 93.4% sand, 3.6% silt, 3.0% clay, pH 5–6) free of insecticidal residues was collected in Adams Co., Wisconsin. Utilizing the method described by Lichtenstein and Schulz (1959), we applied acetone solutions of [¹⁴C]phosphate to the soil to yield a dry weight concentration of 1 ppm (4.3 μCi/700 g of soil). Aliquots of the treated soil were combusted to ¹⁴CO₂ and subsequently analyzed by liquid scintillation counting (LSC) to determine the actual amount of radiocarbon present. Results obtained later were expressed in percent of the insecticidal dose determined by the initial soil analyses following soil treatment.

Plant Growth Procedures. The insides of 36 paper cartons (9 × 8.5 cm diameter) were lined with plastic bags and then filled with 700 g of moist [¹⁴C]phosphate-treated sandy soil each. One-hundred milliliters of modified Hoagland's nutrient solution (Hoagland and Arnon, 1938) were added to the soil in each carton, each of which was then placed into a second plastic bag and sealed. Eight (corn, peas) or twenty-five (oats) seedlings were planted per carton through perforations in the plastic cover, and the "initial weight" of each of the assembled cartons was recorded. Before, the plants were placed into the environmental conditions as described below, they were held for 5 days at room temperature to grow tall enough so that cotton plugs could be inserted around the base of each plant growing through the perforations in the plastic cover. Water lost was replaced on a daily basis with distilled water added through a temporarily unplugged perforation in the plastic cover. Every third day, soil in the cartons was watered with Hoagland's nutrient solution.

Extraction and Analyses. Plant roots, plant tops, and soils in which the plants had grown were separated and extracted with a mixture of acetone-methanol-benzene (1:1:1) as described by Lichtenstein et al. (1973). Benzene and water extraction phases, as well as ¹⁴CO₂ resulting from the oxidation of unextractable (bound) residues, were analyzed by LSC as described by Fuhremann and Lichtenstein (1978). Qualitative and quantitative analyses for [¹⁴C]phosphate and its potential metabolites in the benzene phases were performed by TLC, autoradiography, and LSC (Lichtenstein et al., 1978).

In experiments in which oats were grown in closed systems under bell jars, polyurethane traps for lipid-soluble volatiles were extracted with hexane. ¹⁴CO₂ evolving from the soil-plant system was trapped in a NaOH trap and analyzed as described by Walter-Echols and Lichtenstein (1978).

EXPERIMENTAL PROCEDURES

The effects of combinations of different light intensities and temperatures on the uptake and metabolism of [¹⁴C]phosphate by plants were investigated in facilities of the Biotron at the University of Wisconsin, Madison. A 2 × 2 square design of crossed gradients of light intensity (500 and 3000 ft-c) and temperature (13 and 28 °C) was utilized. Relative humidities averaged 62% and 35% at temperatures of 13 and 28 °C, respectively. A 15-h light, 9-h dark photoperiod was maintained at all gradient positions. Triplicate cartons containing corn, oats, or peas were prepared as described and then placed in each of the four gradient positions of 500 ft-c at 13 °C, 3000 ft-c at 13 °C, 500 ft-c at 28 °C, and 3000 ft-c at 28 °C. Corn and oats were grown in these conditions for 10 days whereas the slower growing peas were allowed to grow for 12 days. The

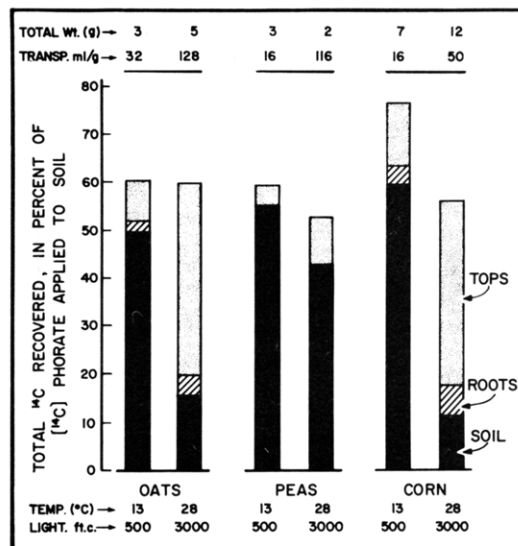


Figure 1. Effects of temperature and light on the fate of [¹⁴C]phosphate in soil and on the translocation of radiocarbon into plants grown in open systems for 10 (oats, corn) or 12 days (peas) under the above conditions in the insecticide-treated soil. Data for pea roots are not available. Results are averages of three replicated tests. Total wt (g): total weight of plant tops harvested. Transp. ml/g: milliliters of water transpired per gram of fresh plant tops.

plant tops, roots, and soils were then separated, extracted, and analyzed as described above.

To determine the extent to which radiocarbon was released as ¹⁴CO₂ or volatilized in another form, a companion experiment was conducted in a closed system with oats as the only crop. Duplicate cartons containing [¹⁴C]phosphate-treated soil plus 25 oat seedlings each were incubated for 5 days as described to obtain a uniform plant height and then covered with bell jars (Anderegg and Lichtenstein, 1981). They were then incubated for 10 days in each of the four gradient positions of light intensity and temperature. The system consisted of a bell jar to cover the sample, a polyurethane plug to trap lipid-soluble ¹⁴C volatiles, and a NaOH trap to capture ¹⁴CO₂ as described by Anderegg and Lichtenstein (1981). Since this environment under bell jars greatly reduced the transpiration rate of the plants, they required addition of water only once throughout the 10-day period. The NaOH in the ¹⁴CO₂ traps was replaced and analyzed for ¹⁴C content on a daily basis. At the end of the incubation, the systems were dismantled, and the soil, plants, and polyurethane were extracted and analyzed by LSC as described above.

RESULTS AND DISCUSSION

To obtain a general idea about the effects observed with the total soil-plant systems, results obtained at the extreme conditions of 13 °C, 500 ft-c, and 28 °C, 3000 ft-c, were first expressed as total amounts of ¹⁴C recovered from all plant material harvested and from the soils in which these plants had grown (Figure 1). At low temperatures and low light intensities more of the applied ¹⁴C remained in the soil and less was translocated into plant tops, while at the extreme condition of 28 °C, 3000 ft-c, less of the totally recovered ¹⁴C remained in the soil and more was translocated into plant tops than at the lower temperature and light intensity.

Corn, a C₄ plant, grows faster than C₃ plants such as oats and peas, particularly in hot climates, but transpires less water (Black, 1973). This was also demonstrated in our experiments (Figure 1, top) where 7–12 g of corn tops had been produced as opposed to 2–5 g observed with oats and

Table I. Uptake and Metabolism of Soil-Applied [¹⁴C]Phorate by Oat, Pea, and Corn Tops,^a As Affected by Light Intensity and Temperature

plant tops	¹⁴ C recovered per g of fresh tops							
	13 °C				28 °C			
	500 ft-c ^b		3000 ft-c ^b		500 ft-c		3000 ft-c	
	% appl ^c	% T ^d	% appl	% T	% appl	% T	% appl	% T
oats								
benzene ^e	1.38 ± 0.13	50	2.24 ± 0.02 ^f	54	2.62 ± 0.67 ^f	47	2.92 ± 0.05 ^f	38
water ^e	1.21 ± 0.30 ^f	44	1.64 ± 0.14 ^{f,g}	40	2.34 ± 0.42 ^g	42	3.83 ± 0.08	51
bound ^e	0.18 ± 0.05 ^f	6	0.27 ± 0.02 ^f	6	0.63 ± 0.11	11	0.84 ± 0.18	11
total	2.76 ± 0.46	100	4.14 ± 0.14	100	5.59 ± 1.19	100	7.59 ± 0.19	100
peas								
benzene	0.96 ± 0.10 ^f	60	0.89 ± 0.23 ^f	55	2.54 ± 0.46 ^g	59	3.17 ± 0.77 ^g	48
water	0.36 ± 0.06 ^f	23	0.38 ± 0.02 ^f	23	1.27 ± 0.05	29	1.88 ± 0.28	29
bound	0.27 ± 0.02 ^f	17	0.36 ± 0.00 ^f	22	0.51 ± 0.13	12	1.48 ± 0.09	23
total	1.59 ± 0.16 ^f	100	1.63 ± 0.24 ^f	100	4.32 ± 0.60	100	6.53 ± 1.12	100
corn								
benzene	1.17 ± 0.00 ^f	60	1.10 ± 0.10 ^f	55	0.85 ± 0.15 ^f	47	1.52 ± 0.32	48
water	0.67 ± 0.05	34	0.78 ± 0.05 ^f	39	0.83 ± 0.03 ^f	46	1.27 ± 0.07	41
bound	0.12 ± 0.01 ^f	6	0.12 ± 0.02 ^f	6	0.13 ± 0.01 ^f	7	0.35 ± 0.04	11
total	1.95 ± 0.06 ^f	100	2.01 ± 0.16 ^f	100	1.81 ± 0.17 ^f	100	3.14 ± 0.29	100

^a Oats or corn were grown under the above conditions in insecticide-treated soil for 10 days and peas for 12 days. Results are means ± SD of three replicates. ^b Light intensities of 500 or 3000 foot candles. ^c % appl: recovered in percent of [¹⁴C]phorate applied at 1 ppm (4.3 μCi) to 700 g of a Plainfield sand. ^d % T = ¹⁴C in percent of total radiocarbon recovered. ^e Benzene and water extraction phases of plant tops. Bound = unextractable ¹⁴C. ^{f,g} In each horizontal line, means followed by the same letter (*f* or *g*) are not significantly different (5% level, Duncan's new multiple range test).

peas. Yet at 28 °C and 3000 ft-c corn transpired only 50 mL of water/g of tops, while oats and peas transpired 128 and 116 mL of water/g of tops, respectively. Since the transpiration stream has been shown to be a primary factor in transporting insecticides from soils into plants (Anderegg and Lichtenstein 1981), it was not surprising that the amounts of ¹⁴C recovered under conditions of 28 °C, 3000 ft-c, from 12 g of corn tops were nearly identical with the amounts found in 5 g of oat tops grown under the same conditions. Calculated on a per gram basis, however, corn tops contained less than half the amount (3.14% of applied, Table I) than that observed with oats (7.59% of applied).

Since growth rates were not the same among three replicate experiments with one plant species and more so with different plant species, data obtained from plants were, for comparison purposes, expressed as amounts of radiocarbon recovered per gram fresh weight of plant tops. With soils, however, data were expressed per total soil weight.

The uptake and metabolism of soil-applied [¹⁴C]phorate by oat, pea, and corn tops are summarized in Table I, showing the amounts of organic-soluble, water-soluble, and unextractable (bound) radiocarbon recovered from plant tops. It is evident that an increase in light intensity at a constant temperature resulted in an increase of ¹⁴C compounds in plant tops. Increasing the light intensity from 500 to 3000 ft-c at 13 °C only caused an increase of total radiocarbon content in oats, while the same experiment conducted at a temperature of 28 °C resulted in significant increases in the uptake of ¹⁴C compounds by oat, pea, and corn tops by factors of 1.34, 1.51, and 1.73, respectively. Also, significantly more water-soluble and bound ¹⁴C compounds had been produced in all three plant species. Results, therefore, indicate that the higher light intensity affected the metabolism of translocated ¹⁴C compounds, primarily at 28 °C.

Increasing the temperature from 13 to 20 °C, but at a constant light intensity of 500 ft-c, resulted in a 2- and 2.7-fold increase of total radiocarbon translocated into oat and pea tops, respectively, but not in corn. The same experiment conducted at 3000 ft-c, however, showed significant increases in the ¹⁴C content of tops of all three

Table II. [¹⁴C]Phorate Residues Remaining in Soils in Which Oats, Peas, or Corn Had Grown^a under Different Light Intensities and Temperatures

total soil from	¹⁴ C recovered from soils			
	13 °C, 500 ft-c ^b		28 °C, 3000 ft-c ^b	
	% appl ^c	% T ^d	% appl	% T
oats				
benzene ^e	43.39 ± 1.72	87	7.74 ± 0.92 ^f	51
water ^e	1.26 ± 0.09	3	0.53 ± 0.27 ^h	4
bound ^e	5.07 ± 1.26	10	6.81 ± 1.42	45
total	49.72 ± 1.40	100	15.08 ± 2.58 ^f	100
peas				
benzene	46.39 ± 1.44	84	30.36 ± 1.23 ^f	72
water	1.65 ± 0.19	3	1.77 ± 0.06	4
bound	7.25 ± 0.67	13	10.36 ± 1.85	24
total	55.29 ± 1.96	100	42.49 ± 1.34 ^f	100
corn				
benzene	54.59 ± 4.51	91	6.48 ± 0.87 ^f	58
water	1.61 ± 0.24	3	0.39 ± 0.14 ^g	3
bound	3.95 ± 1.51	6	4.38 ± 0.82	39
total	60.15 ± 5.88	100	11.25 ± 0.75 ^f	100

^{a-e} As in Table I. ^{f-h} For each soil, data obtained at 28 °C, 3000 ft-c, are significantly different from respective data at 13 °C, 500 ft-c, at the 0.1% (*f*), 1% (*g*), or 5% (*h*) level (Student's *t* test).

plant species. Higher temperatures caused in most cases an increase in the production of water-soluble and bound ¹⁴C compounds, indicating a direct effect on the metabolism of the originally soil applied [¹⁴C]phorate.

The relative distribution of benzene-soluble, water-soluble, and bound radiocarbon was also expressed in percent of the total radiocarbon recovered (% T in Table I). This distribution was quite similar in all plants under the four experimental conditions (38–60% benzene-soluble ¹⁴C, 23–51% water-soluble ¹⁴C, and 6–23% unextractable, bound ¹⁴C compounds).

Only those soils were extracted and analyzed in which oats, peas, or corn had grown under the two extreme experimental conditions of 13 °C, 500 ft-c, and 28 °C, 3000 ft-c. Results are summarized in Table II and indicate that total recoveries of ¹⁴C compounds remaining in the soil at 13 °C, 500 ft-c, were 3.3, 1.3, and 5.4 times larger than those recovered from soils that were incubated at 28 °C, 3000

Table III. Production of [¹⁴C]Phorate Metabolites in Soils and Plants^a As Affected by Light Intensity^b and Temperature

benzene-soluble compounds ^d	benzene-soluble radiocarbon ^c recovered from							
	soils (total weight)				tops (per g fresh weight)			
	13 °C, 500 ft-c		28 °C, 3000 ft-c		13 °C, 500 ft-c		28 °C, 3000 ft-c	
	% appl ^e	% T ^f	% appl	% T	% appl	% T	% appl	% T
oats								
PS-S	3.7 ± 0.4	9	1.9 ± 0.2 ^h	25	ND ^j		ND	
PS-SO	30.5 ± 2.1	70	3.3 ± 0.4 ^g	42	0.8 ± 0.1	57	1.2 ± 0.1 ^h	40
PS-SO ₂	8.6 ± 0.6	20	2.4 ± 0.4 ^g	31	0.4 ± 0.1	29	0.8 ± 0.0 ^g	27
PO-SO	0.3 ± 0.0	1	0.1 ± 0.0 ^g	1	0.1 ± 0.0	7	0.4 ± 0.0 ^g	13
PO-SO ₂	0.2 ± 0.0	<1	0.1 ± 0.0 ^h	1	0.1 ± 0.0	7	0.6 ± 0.0 ^g	20
total	43.3 ± 1.7	100	7.8 ± 0.9 ^g	100	1.4 ± 0.1	100	3.0 ± 0.1 ^g	100
peas								
PS-S	3.0 ± 0.1	6	1.4 ± 0.1 ^g	4	ND		ND	
PS-SO	31.0 ± 1.1	67	15.7 ± 1.0 ^g	52	0.6 ± 0.1	67	1.7 ± 0.3 ^h	53
PS-SO ₂	11.8 ± 1.0	25	13.0 ± 0.8	43	0.2 ± 0.0	22	1.0 ± 0.4 ⁱ	31
PO-SO	0.3 ± 0.0	1	0.2 ± 0.0 ^h	<1	0.1 ± 0.0	11	0.5 ± 0.1 ^h	16
PO-SO ₂	0.3 ± 0.1	1	0.2 ± 0.1	<1	ND		ND	
total	46.4 ± 1.4	100	30.5 ± 1.2 ^g	100	0.9 ± 0.1	100	3.2 ± 0.8 ^h	100
corn								
PS-S	9.7 ± 1.5	18	2.0 ± 0.1 ^g	32	ND		ND	
PS-SO	37.4 ± 3.0	69	2.5 ± 0.2 ^g	41	0.6 ± 0.0	55	0.6 ± 0.1	40
PS-SO ₂	6.8 ± 1.0	12	1.5 ± 0.2 ^g	25	0.4 ± 0.0	36	0.5 ± 0.2	34
PO-SO	0.3 ± 0.1	<1	tr ^j	0	0.1 ± 0.0	9	0.2 ± 0.0 ^h	13
PO-SO ₂	0.2 ± 0.0	<1	0.1 ± 0.0 ⁱ	2	tr		0.2 ± 0.0 ^h	13
total	54.4 ± 4.4	100	6.1 ± 0.4 ^g	100	1.1 ± 0.0	100	1.5 ± 0.3	100

^a Soils, treated with [¹⁴C]phorate at 1 ppm (4.3 μCi), were analyzed after oats or corn had grown in them under the above conditions for 10 days and peas for 12 days. Results are means ± SD of triplicate tests. ^b Light intensities of 500 or 3000 ft-c. ^c Data for benzene-soluble ¹⁴C are presented in Tables I (plant tops) and II (soils). ^d Determined by thin-layer separation, autoradiography, and LSC: PS-S = phorate; PS-SO = phorate sulfoxide; PS-SO₂ = phorate sulfone; PO-SO = phoratoxon sulfoxide; PO-SO₂ = phoratoxon sulfone. ^e % appl: recovered in percent of [¹⁴C]phorate applied to soil. ^f % T: ¹⁴C in percent of total benzene-soluble radiocarbon. ^{g-i} For soils or tops of each plant, data obtained at 28 °C, 3000 ft-c, are significantly different from respective data at 13 °C, 500 ft-c, at the 0.1% (g), 1% (h), or 5% (i) level (Student's *t* test). ^j ND, nondetectable; tr, trace.

Table IV. Uptake and Metabolism of [¹⁴C]Phorate by Oats Grown in a Closed System for 15 Days in [¹⁴C]Phorate-Treated Soil at Different Light Intensities and Temperatures

	¹⁴ C recovered, % of [¹⁴ C]phorate applied to soil ^a			
	13 °C		28 °C	
	500 ft-c ^b	3000 ft-c ^b	500 ft-c	3000 ft-c
soil (S)				
benzene ^c	68.34 ± 0.06 ^d	66.64 ± 1.90 ^d	59.18 ± 2.58	53.16 ± 0.79
water ^c	1.78 ± 0.08 ^d	1.62 ± 0.12 ^d	1.63 ± 0.17 ^d	1.65 ± 0.03 ^d
bound ^c	7.48 ± 0.67 ^d	6.70 ± 0.15 ^d	7.22 ± 1.72 ^e	8.04 ± 1.08 ^e
total	77.62 ± 0.53 ^d	74.98 ± 1.63 ^d	68.02 ± 4.47 ^e	62.85 ± 0.32 ^e
greens (G)				
benzene	0.66 ± 0.19	1.41 ± 0.16 ^d	1.74 ± 0.04 ^d	3.16 ± 0.11
water	2.43 ± 0.27 ^d	3.40 ± 0.16 ^d	6.00 ± 0.25	10.64 ± 0.71
bound	0.72 ± 0.02 ^d	0.71 ± 0.06 ^d	1.91 ± 0.11	3.27 ± 0.04
total	3.81 ± 0.09	5.51 ± 0.37	9.64 ± 0.09	17.06 ± 0.77
roots (R)				
benzene	1.39 ± 0.30 ^{d,e}	1.57 ± 0.04 ^d	1.26 ± 0.08 ^{d,e}	1.04 ± 0.18 ^e
water	0.19 ± 0.01 ^d	0.24 ± 0.01	0.20 ± 0.00 ^d	0.30 ± 0.02
bound	1.55 ± 0.01	1.85 ± 0.07	2.37 ± 0.13	2.60 ± 0.04
total	3.13 ± 0.30 ^d	3.66 ± 0.02 ^{d,e}	3.83 ± 0.21 ^e	3.93 ± 0.16 ^e
total (G + R)	6.94 ± 0.19	9.17 ± 0.39	13.47 ± 0.30	20.99 ± 0.93
¹⁴ CO ₂ evolved (C)	1.12 ± 0.07 ^d	1.04 ± 0.01 ^d	7.20 ± 0.81 ^e	6.33 ± 0.68 ^e
total (S + G + R + C)	85.68 ± 0.41 ^d	85.19 ± 1.24 ^d	88.70 ± 4.97 ^d	90.17 ± 0.57 ^d

^a [¹⁴C]Phorate was applied at 1 ppm (4.3 μCi) to a Plainfield sand. Results are averages of duplicate tests. ^b Light intensities of 500 and 3000 ft-c. ^c Benzene and water extraction phases. Bound = unextractable ¹⁴C. ^{d,e} In each horizontal line, means followed by the letters *d* or *e* are not significantly different (5% level, Duncan's new multiple range test).

ft-c, with oats, peas, or corn, respectively. Most insecticide residues were recovered from soil in which corn had grown at 13 °C, 500 ft-c (60% of applied recovered), and least from soil in which corn had grown at 28 °C, 3000 ft-c (11% of applied recovered). The majority of ¹⁴C compounds recovered from soils was in all cases in benzene-soluble form, amounting to 84–91% of all the radiocarbon recovered at 13 °C, 500 ft-c, and to 51–72% of that recovered at 28 °C, 3000 ft-c (% *T* in Table II). Water-soluble ¹⁴C compounds represented only 3–4% of the total radiocarbon

recovered under both experimental conditions. Formation of bound ¹⁴C compounds in these soils amounted to only 6–13% at 13 °C, 500 ft-c, but had increased to 24–45% of the total ¹⁴C recovered at 28 °C, 3000 ft-c.

To identify phorate and some of its metabolites, benzene-soluble radiocarbon recovered from both soils and plant tops grown at 13 °C, 500 ft-c, and 28 °C, 3000 ft-c, was also analyzed by TLC, autoradiography, and LSC. Results obtained are summarized in Table III. In soils amounts of the originally applied phorate (PS-S) recovered

were relatively small, while phorate sulfoxide (PS-SO) was the major constituent. Expressed in percent of total benzene-soluble ^{14}C recovered (% *T* in table III), phorate sulfoxide represented 67–70% of the total benzene-soluble radiocarbon recovered at 13 °C, 500 ft-c, and 42–52% at 28 °C, 3000 ft-c. With phorate sulfone (PS-SO₂) relative amounts (% *T* in Table III) of these residues increased at the higher temperature and greater light intensity from 21 to 31%, 25 to 43%, and 12 to 24% in soils incubated with oats, peas, or corn, respectively.

With plant tops data were expressed on a per gram fresh weight basis (Table III). Contrary to soils, no phorate (PS-S) was recovered from any of the plant tops, while, similar to soils, phorate sulfoxide was the major compound recovered from plants and represented 40–67% of all the benzene-soluble compounds identified. The amounts of phoratoxon sulfoxide (PO-SO) and phoratoxon sulfone (PO, SO₂) in plant tops represented 9–20% of all the benzene-soluble radiocarbon as opposed to 1–1.6% observed with soils.

Experiments described so far were conducted with open soil-plant systems and could not account for ^{14}C compounds lost by volatilization. As demonstrated in Figure 1, total amounts of radiocarbon recovered from the soil-plant systems under open conditions ranged from 53 to 77% of the soil-applied dose and left 23–47% unaccounted for. To determine the amounts of volatile radiocarbon such as $^{14}\text{CO}_2$ or lipid-soluble compounds, experiments were therefore conducted with oats grown in closed systems under bell jars as described. Previous experiments had shown that a reduction of water transpiration in closed soil-plant systems also resulted in a reduction of the translocation of soil-applied radiocarbon into plant tops (Anderegg and Lichtenstein, 1981). Data obtained in such a way are therefore not comparable to those obtained under open conditions.

Results obtained from our present experiments conducted under closed conditions with soils and plants were expressed as total amounts of radiocarbon recovered in percent of the initially soil-applied [^{14}C]phorate. As shown in Table IV, total recoveries from soils, oats, and volatiles were similar under all four experimental conditions and ranged from 85.2 to 90.2% of the soil-applied radiocarbon. As discussed under Plant Growth Procedures, oats had to be grown in insecticide-treated soil for 5 days prior to being covered with bell jars. It is possible, therefore, that 10–15% of the originally applied radiocarbon could have been lost during that time. An increase in light intensity from 500 to 3000 ft-c at 28 °C significantly increased the amounts of ^{14}C compounds translocated into oat tops from 9.6 to 17.1% of the soil-applied radiocarbon. Of the 17.1%, 10.6% were water-soluble, 3.2% were benzene-soluble, and 3.3% were bound (unextractable). Increasing the light intensity at the lower temperature of 13 °C yielded similar results to those observed at 28 °C but not as pronounced.

Increasing the temperature from 13 to 28 °C at 3000 ft-c also resulted in significant changes in the amounts of ^{14}C compounds recovered from soils and plants as well as in the production of $^{14}\text{CO}_2$. While in soils at 28 °C the amount of ^{14}C compounds had been reduced from 75 to

63% of applied, they had increased in oat tops from 5.5 to 17.1% of applied. Also, the amount of $^{14}\text{CO}_2$ produced and trapped had increased from 1 to 6.3% of applied radiocarbon. No volatile lipid-soluble radiocarbon was recovered. The decrease of ^{14}C compounds in soils was due to a decrease in benzene-soluble radiocarbon only, while the increase in ^{14}C compounds in oat tops was the result of an increase in benzene-soluble, water-soluble, and bound radiocarbon.

In summary, data indicate that changes in the intensity of light or temperature or in combination affected the environmental fate of [^{14}C]phorate in soil and its translocation and metabolism in plants grown in these soils. Increasing the intensity of light, particularly at the higher temperature of 28 °C, resulted in decreased recoveries of the insecticide from soils and an increased translocation of ^{14}C compounds into plant tops. However, the most pronounced effects were observed when temperature was increased from 13 to 28 °C, particularly at the greater light intensity of 3000 ft-c. This was reflected not only by the presence of increased amounts of ^{14}C compounds in plant tops but also by an accelerated metabolism of the insecticide as indicated by increased production of water-soluble, bound ^{14}C compounds and $^{14}\text{CO}_2$.

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