(2,4-Dichlorophenoxy)acetic Acid Exposure Received by Aerial Application Crews during Forest Spray Operations

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In three helicopter spray operations, forest workers were monitored for exposure to and internal dose of (2,4-dichlorophenoxy)acetic acid (2,4-D). Levels of 2,4-D were measured in air near the breathing zone, on denim patches to estimate dermal exposure, and in the urine excreted for 2 days before and 5 days after the spraying to determine internal dose. Each crew made two applications about 1 week apart to compare exposure from crew members wearing customary clothing and following normal precautions (T-1) with that of the same crew members wearing protective apparel and following special hygienic practices (T-2). External exposure was low with the highest level at 0.0911 mg/kg of body weight for a batchman in T-1. The total internal dose determined by urine analyses ranged from nondetectable to 0.0557 (in T-1) or 0.0237 (in T-2) mg/kg of body weight. Those crewmen working most closely with the spray concentrate or handling spray equipment (pilots, mechanics, and batchman–loaders) showed the highest doses. Protective clothing and good hygienic practices limited exposure. On the basis of analyses of toxic levels of 2,4-D in laboratory animals, human exposure levels in these tests were well below that which might endanger health.

Considerable research has shown the effectiveness, economic importance, toxicological effects, and environmental behavior of herbicides. However, only a limited number of studies have measured amounts and disposition of herbicide actually absorbed by applicators (Sauerhoff et al., 1977; Kolmodin-Hedman et al., 1979). Such knowledge is important for the safety of those whose use herbicides and for the understanding of those who regulate their use [e.g., U.S. Environmental Protection Agency (1978)]. This kind of information was recently acquired for the herbicide (2,4,5-trichlorophenoxy)acetic acid (2,4,5-T) (Lavy, 1978; Lavy et al., 1980a,b; Ramsey et al., 1978). The purpose of this study was to provide similar information for (2,4-dichlorophenoxy)acetic acid (2,4-D).

The rapid degradation of 2,4-D makes it one of the least persistent herbicides in the environment (Norris, 1966, 1970; Lavy et al., 1973; WSSA Herbicide Handbook Committee, 1979). Furthermore, the long history of 2,4-D use with no reports of ill effects to applicators suggested that harmful levels were probably not being absorbed. Nevertheless, scientific data were needed to document the extent of exposure occurring to workers under actual field conditions. The results of this study, when used in conjunction with toxicological data, provide a meaningful evaluation of applicator safety during use of 2,4-D under various conditions.

Techniques have been developed in recent years to measure external exposure to pesticides (Durham and Wolfe, 1962) and internal phenoxy herbicide dose as measured in the urine excreted (Sauerhoff et al., 1977; Lavy et al., 1980a). The 2,4,5-T present in the urine has been shown to be a reliable indicator of the dose received during application of 2,4,5-T spray (Lavy, 1978; Gehring et al., 1973). Since 2,4-D is quite similar structurally, and since it is metabolized in a similar fashion (Sauerhoff et al., 1977), the same technique has been used to ascertain the dose of 2,4-D absorbed by workers during application (Kolmodin-Hedman et al., 1979).

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The objectives of this study were (1) to measure both external exposure and internal dose received by helicopter crews spraying 2,4-D in the forest, (2) to determine whether protective clothing significantly altered these measurements, and (3) to evaluate the relationship between exposure or dose and the worker's duties.

MATERIALS AND METHODS

Measurements Taken. Tests were designed to determine the quantity of 2,4-D in the ambient air of the worker's breathing zone, the quantity of 2,4-D that came into contact with denim patches attached to the worker's clothing, and the quantity and rate of 2,4-D that was subsequently excreted in the urine of each worker.

Air Samples. Battery-powered air sampling monitors were attached to all workers involved in the spraying program to provide an estimate of respiratory exposure to 2,4-D ester. The monitors contained amberlite XAD-2 resin, which is effective in trapping airborne vapors and spray droplets of 2,4-D esters (Johnson et al., 1977). After the air monitors were exposed during the treatment period, the tubes containing the resin were removed and placed in small, airtight containers until analysis.

For these analyses, the total volume of air inhaled was estimated by multiplying the rate (1740 L/h) at which a person doing this kind of work breathes (Durham and Wolfe, 1962) by the total time of the exposure period (148 min). The total volume of air inhaled multiplied by the concentration of 2,4-D (micrograms per liter) from the resin of the air monitors gives the total amount of 2,4-D inhaled. This amount is expressed on a basis of micrograms per kilogram of body weight.

Patches. Before the spray operation, denim patches were attached to crew members' clothing near bare skin areas. For estimation of exposure to the wrist area, a 2.5 × 15 cm strip was stapled to each shirt cuff. So that exposure to the bare skin of the head and neck could be estimated, one 2.5 × 40 cm strip was stapled to the back of the collar of the shirt, extending to the points of the collar on each side, and another 2.5 × 40 cm strip was similarly attached to the hat band, extending from the front and around both sides toward the back. The patches were attached to and removed from workers by persons not exposed to the spray material and were then shipped to the analytical laboratory in individual glass containers

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Table I. Summary of Batching, Loading, and Spraying Information

	T-1			T-2		
	crew 1	crew 2	crew 3	crew 1	crew 2	crew 3
batching operation						
time required (approx.), min	15	5	60[a]	6	5	18
volume mixed, gal	1000	1000	1000	1000	1000	1000
loading operation						
number of loads	13	14	17	13	14	17
volume/load (approx.), gal	80	70	60	80	70	60
time required/load (approx.), min	0.5	1	1	0.5	1	1
total time loading, min	9	14	18	7	14	24
spraying operation						
time required/load (approx.), min	3	2	3.5	2.5	2	2.5
total time flying,[b] min	43	29	60	34	27	45

[a] The transfer pump failed to operate, so the batching operation was conducted manually by using pails. [b] The actual "trigger time" for spraying was about half of the flying times.

immediately after the spray operation.

In addition to height and weight measurements, a photograph was taken of each worker in spray attire to determine the area of bare skin exposed, based on values provided by Durham and Wolfe (1962). The area of bare skin, in conjunction with the amount of 2,4-D deposited on the denim patches (known area), was used to estimate dermal exposure.

Urine Collection. The pharmacokinetic behavior of 2,4-D and 2,4,5-T in humans has been established for a 6-day period (Sauerhoff et al., 1977; Gehring et al., 1973). The total collection period in this study covered 2 days before the spraying occurred, the spray day, and at least 5 days after each spray application. Polyethylene-lined containers (2.5-L capacity) were used by each crew member to collect all urine excreted over consecutive 12-h intervals throughout the test. The urine samples collected prior to spraying were used to detect background levels, if any, of 2,4-D present in the urine and to check for interferences that might confound analysis. Workers were instructed to avoid contaminating the urine. The urine was kept in a cool location before being transported at 3–4-day intervals to the laboratory for analysis.

Crew Description. Three different helicopter crews (designated crews 1, 2, and 3) participated in the study. Each crew was comprised of a helicopter pilot, mechanic, batchman–loader, supervisor, and two observers. Observers were included in the study to provide an estimate of the 2,4-D dose received by individuals who were not directly involved in the spray application but were 25–175 yards from the helicopter loading zone at the time the spraying was done.

Test Description. Each crew performed two applications, which were approximately 1 week apart. In the first treatment (T-1), crew members made use of conventional spray techniques and performed their normal duties using ordinary precautions (Lavy, 1980). They followed label instructions and other legal regulations but received no additional guidance from research personnel.

A second treatment (T-2), in which additional precautions were used, was conducted following the conclusion of the T-1 phase of the study. During T-2 the workers wore special protective clothing consisting of disposable Tyvek coveralls. (Tyvek is the trade name for Du Pont's spun-bonded olefin fabric, consisting of a lightweight paper covered with a durable plastic film.) In addition, pilots wore normal flying gloves and headgear, mechanics, batchman–loaders, and supervisors wore chemically impervious gloves and boots, clean hats, and goggles, and observers wore cotton or rubber gloves, clean hats, and goggles. During T-2 it was permissible for research personnel to suggest to crew members how to minimize exposure. For example, crew members were instructed to wash their hands before rest stops and meals and also to take showers and change into clean clothing soon after the spray operation.

Table II. Recovery Data for Air, Patch, and Urine Analyses

analyses of fortified samples	no. of replicates	2,4-D acid equiv added[a]	av % recovery ± SD
air[b]		μg	
laboratory	4	0.068	87 ± 19
	4	0.36	81 ± 0.8
	4	0.72	78 ± 3
	4	3.5	80 ± 6
field	4	18.0	115 ± 13
	3	83.0	71 ± 2
patches[c]		mg	
laboratory	4	0.0037	156 ± 17
	4	0.0074	122 ± 4
	4	0.015	95 ± 12
	4	0.030	101 ± 9
field	8	0.038	118 ± 9
	8	0.075	104 ± 13
	8	0.375	105 ± 9
	8	0.750	112 ± 13
urine[d]		ppm	
laboratory	16	0.0386	98 ± 54
	20	0.565	74 ± 7
	12	2.300	73 ± 7
field	6	0.0328	98 ± 48
	12	0.0645	86 ± 26
	12	0.246	70 ± 11
	12	0.842	73 ± 10

[a] The solution used to fortify samples was a dilution of Esteron 99 Concentrate in hexane. [b] The limit of detection ($S/N = 2$) for air monitors was established as 0.05 μg. Only one air monitor collected from the workers indicated the presence of 2,4-D, and it was within the range of 0.068–0.36 μg shown above. The average recovery value, which includes trapping efficiency, for fortified standards in this range was 84% [(87 + 81)/2]. Thus, an 84% recovery figure was used to correct the value from the air monitor worn by worker 33 as shown in Table III. [c] The limit of detection ($S/N = 2$) was established as 0.0037 mg. Most of the 2,4-D values for patch samples worn by workers fell within the range shown above where 100% recovery (within experimental error) was obtained. Thus, there was no need to correct the values for patch samples collected from workers for percent recovery. [d] The limit of detection ($S/N = 2$) was established as 0.04 ppm. Urine samples shown in Table V collected from workers during the study were corrected for percent recovery by using a sliding scale as constructed from the above recovery data.

Both treatments were designed with the intent that the only exposure to phenoxy herbicides would occur on the actual spray day of T-1 and T-2. All selected crew mem-

Table III. Estimation of Respiratory Exposure to 2,4-D As Determined from Analyses of Air Monitors Worn by Workers[a]

worker		T-1 (ordinary precautions)				T-2 (special precautions)			
no.	wt, kg	2,4-D on resin,[b] μg	air vol sampled, L	concn, μg/L	estimated respiratory exposure/body wt, μg/kg	2,4-D on resin,[b] μg	air vol sampled, L	concn, μg/L	estimated respiratory exposure/body wt, μg/kg
11	89.0	nd	16.8	nd	nd	nd	7.59	nd	nd
12	74.9	nd	19.9	nd	nd	nd	11.00	nd	nd
13	79.5	nd	24.0	nd	nd	nd	23.34	nd	nd
14	97.6	nd	17.9	nd	nd	nd	20.52	nd	nd
15	72.6	nd	15.4	nd	nd	nd	15.19	nd	nd
16	72.6	nd	14.1	nd	nd	nd	10.70	nd	nd
21	68.6	nd	18.2	nd	nd	nd	14.41	nd	nd
22	95.3	c	c	c	c	nd	18.50	nd	nd
23	90.8	nd	20.0	nd	nd	nd	19.45	nd	nd
24	102.2	nd	18.6	nd	nd	nd	20.75	nd	nd
25	84.0	nd	24.1	nd	nd	nd	9.76	nd	nd
26	72.6	nd	17.2	nd	nd	nd	12.17	nd	nd
31	88.5	nd	30.8	nd	nd	nd	8.27	nd	nd
32	89.9	nd	23.8	nd	nd	nd	17.03	nd	nd
33	79.5	0.13	23.1	0.0056	0.30[d]	c	c	c	c
34	90.8	c	c	c	c	nd	18.94	nd	nd
35	79.5	nd	32.1	nd	nd	nd	14.60	nd	nd
36	74.9	nd	21.9	nd	nd	nd	15.31	nd	nd

[a] The limit of detection (S/N = 2) was 0.05 μg. Values which were below the limit of detection are represented by nd (not detected). [b] All values have been corrected for percent recovery (84%) according to data presented in Table II. [c] Pump failure precluded meaningful analyses of these samples. [d] Respiratory exposure per body weight for worker 33 was determined as follows: (0.13 μg of 2,4-D/23.1 L of air × 1740 L of air/ha × 148 min × 1 h/60 min)/79.5 kg of body weight = 0.30 μg of 2,4-D/kg of body weight.

bers claimed to have had no known exposure to 2,4-D for at least 2 weeks prior to the study. As a precautionary measure, however, urine samples were collected for the 2 days preceding T-1. Seven days elapsed between the spray days in T-1 and T-2 for crew 1, and 6 days elapsed between the 2 spray days for crews 2 and 3.

Treatment Description. Personnel engaged in supervising and applying the herbicide treatment were trained, licensed, and certified by the appropriate state and federal agencies. The spray applications complied with state and federal regulations and were representative of routine aerial treatments in forestry.

The application areas, typical of the Pacific Northwest, were located near Raymond, WA, Cottage Grove, OR, and Gardiner, OR, for crews 1, 2, and 3, respectively. At each geographic location, two sites were selected within 10 miles of each other for the respective T-1 and T-2 applications. Each site consisted of an approximate 100-acre tract within a larger forested area. These tracts contained Douglas fir [*Pseudotsuga menziesii* (Mirb.) Franco] in need of release from competing vegetation.

Treatments were applied by helicopter at each location in late February and early March of 1980. The formulation used was Esteron 99 Concentrate, which contains 4 lb of acid equivalent (a.e.) of 2,4-D/gal as the propylene glycol butyl ether ester. The herbicide was mixed with diesel oil and water at the rate of 0.5:0.5:9 gal, and the resulting mixture was applied at the rate of 10 gal/acre, which provided a 2,4-D application rate of approximately 2 lb of a.e./acre. Therefore, each 100-acre tract received about 1000 gal of this mixture.

Treatments were applied in the early morning hours. Temperatures ranged from 4 to 13 °C, and relative humidities were usually in excess of 80%. Winds were generally calm, with occasional gusts up to 5 mph. Weather conditions were typical for the season and were well within the regulatory restrictions for spraying.

Treatment Logistics. Table I displays the information collected during the treatment phase of the study. With one exception, batching of the 1000 gal of spray mixture took from 5 to 18 min, depending on the pumping system employed. The exception occurred during T-1 when crew 3 required nearly 1 h to transfer the concentrate manually from the drum to the batch truck via 2-gal pails because the pumping system failed to operate.

Loading the spray mixture from the batch truck into the helicopter tanks took 30–60 s/load. The volume per load varied from 60 to 80 gal, depending on payload capacity of the helicopter. The spraying operation took 2–4 min/load, depending on ferry distance. Actual "trigger time" was 1–2 min/load. Total time required for loading and spraying the 1000 gal ranged from 41 to 78 min/treatment. These spray periods were comparable to those in routine forestry operations (American Paper Institute/National Forest Products Association, 1978).

Chemical Recovery Data. Laboratory procedures used to analyze air monitors, patches, and urine were similar to those used by Johnson et al. (1977) or Lavy et al. (1980a). To ensure that no 2,4-D was broken down prior to analysis and to establish the percent recovery for the analytical techniques, we prepared a series of samples fortified with known 2,4-D amounts for each sample type (air; patches; urine) in the field shortly after collection. These were compared to samples fortified similarly at the laboratory just prior to analysis. Limits of detection were established by a signal-to-noise ratio of two (S/N = 2).

Recovery data are shown in Table II. Reported values for experimental samples shown in Tables III–V have been corrected for percent recovery as discussed in Table II. In all cases, the 2,4-D values are reported as the acid form. Phenoxy esters are converted in the body to the acid form, which is then excreted in urine (Gehring et al., 1973).

The Amberlite XAD-2 resin from the air monitors and the denim patches used to intercept 2,4-D spray mist were analyzed by gas chromatographic techniques (Lavy et al., 1980a,b; Johnson et al., 1977). The limits of detection were established as 0.05 μg for the air monitors and 0.0037 mg for the patches.

Urine samples used to measure the dose of 2,4-D received by crew members were analyzed by a modification of a gas chromatographic technique used by Lavy et al. (1980a). When the methyl ester of 2,4-D was prepared, it was found to elute at a retention time similar to those of interfering peaks from the urine. The method was modified by preparing the butyl ester of 2,4-D with BF_3–butanol. The limit of detection was established as 0.04 mg/kg in the urine. Two different columns were used routinely in the ^{63}Ni gas chromatographs to confirm results obtained from air, patch, and urine sample analyses.

RESULTS AND DISCUSSION

Air Samples. Thirty-two of the 33 air monitors which remained functional during the test did not contain any 2,4-D at the limit of detection of 0.05 μg (Table III). The only air monitor containing a detectable amount of 2,4-D was worn during T-1 by the batchman–loader (worker 33), one of the crew members who manually transferred the 2,4-D concentrate from the drum to the batch truck due to a malfunction of the normal pumping system. Subsequent conversations with this worker revealed that odors associated with the concentrate were discernible during the transfer process. Therefore, it is possible that his activity may have accounted for the 2,4-D detected by that particular monitor. The amount detected during the test was equivalent to 0.30 μg of 2,4-D/kg of body weight.

Patch Samples. The amount of 2,4-D deposited on the denim patches attached to each crew member's clothing is shown in Table IV. Levels detected were generally very low, and in many instances no detectable exposure occurred. The exposure that did occur appeared directly related to workers' duties. Batchman–loaders and mechanics usually showed some degree of dermal exposure; observers showed almost none. Observers in crews 2 and 3 were stationed outside the spray areas during the 2,4-D application. However, worker 15, an observer in crew 1, was inadvertently in the spray area during T-2. Table IV shows that his patches received slight amounts of 2,4-D.

Since all patches were placed on the outside of the clothing in both T-1 and T-2, no major differences in patch exposure between the two tests would have been expected. An exception occurred in T-1 for crew 3 (particularly the mechanic, worker 32, and the batchman–loader, worker 33), who manually transferred the concentrate from the drum to the batch truck when the transfer pump did not work. This operation increased the opportunities for exposure to the concentrate, and visual observations of these workers' clothing revealed that certain portions did indeed become contaminated during the transfer process. The transfer pump worked properly for this crew during T-2. This fact probably accounts for the reduced amounts of 2,4-D detected on the patches of the mechanic and batchman–loader in T-2 (Table IV).

Five of the six patches on the headbands of batchman–loaders contained higher amounts of 2,4-D than their other patches (Table IV). These workers attached the quick-couple batch truck hose to the helicopter during reloading. The wind generated by the whirling helicopter blades often prompted the batchman–loaders to hold their hats in place. Although these individuals often wore gloves (always in T-2), the gloves were sometimes contaminated with 2,4-D which could have been easily transferred to the patch on the headbands as they held onto their hats.

Urine Samples. Whether intake of 2,4-D was through dermal, respiratory, or other exposure, the actual dose can be determined by analyzing for 2,4-D in the urine excreted. The total quantity of 2,4-D excreted during T-1 and T-2 (spray day plus 5 days thereafter) was determined by

Table IV. Estimation of Dermal Exposure to 2,4-D As Determined from Analysis of Patches[a]

worker				T-1 (ordinary precautions)					T-2 (special precautions)				
				amount of 2,4-D on patches, mg					amount of 2,4-D on patches, mg				
no.	wt, kg	T-1 dermal exposure area,[b] cm²	T-2 dermal exposure area,[b] cm²	right wrist (37.5 cm²)	left wrist (37.5 cm²)	neck (100 cm²)	head (120 cm²)	estimated dermal exposure/body wt,[c] mg/kg	right wrist (37.5 cm²)	left wrist (37.5 cm²)	neck (100 cm²)	head (120 cm²)	estimated dermal exposure/body wt, mg/kg
11	90	650	650	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
12	75	650	430	0.007	0.007	0.019	0.046	0.0023	0.024	nd	nd	nd	0.0005
13	80	580	580	0.009	nd	0.029	0.056	0.0023	0.008	nd	0.010	0.047	0.00016
14	98	1620	540	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
15	73	1580	540	nd	nd	nd	nd	nd	0.018	0.012	0.035	0.114	0.0045
16	73	760	540	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
21	69	760	760	nd	0.019	0.005	0.004	0.0010	nd	nd	nd	nd	nd
22	95	1470	430	0.048	0.011	nd	0.053	0.0059	0.047	0.596	0.032	0.383	0.0162
23	91	800	540	0.013	0.047	0.015	2.974	0.0911	0.177	0.253	0.008	0.636	0.0216

24	102	800	540	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
25	84	1580	540	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
26	73	760	540	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
31	89	800	800	0.012	nd	nd	0.011	0.0007	0.004	nd	nd	nd	0.0001
32	90	1580	540	0.962	0.055	0.008	0.010	0.0617	0.014	0.007	nd	0.008	0.0006
33	80	800	540	0.356	0.375	0.010	0.458	0.0409	0.048	0.348	0.005	0.042	0.0102
34	91	1580	540	nd	0.008	nd	nd	0.0005	nd	0.134	nd	nd	0.0027
35	80	1620	540	nd	nd	nd	nd	nd	0.170	nd	nd	nd	0.0039
36	75	1580	540	nd	nd	nd	0.007	0.0005	nd	nd	nd	nd	nd

[a] The limit of detection ($S/N = 2$) was 0.0037 mg. Where a value of nd (not detected) was obtained, a zero was used for averaging purposes. [b] The dermal exposure area was calculated after viewing photographs of each worker, reviewing treatment notes, and using values obtained by Durham and Wolfe (1962). [c] The estimated dermal exposure per body weight (milligrams per kilogram) represents the amount of 2,4-D that may be deposited on a worker's skin in relation to his size and apparel, as calculated from [2,4-D on four patches (mg) × dermal exposure area (cm²)]/[total patch area (295 cm²) × body weight (kg)].

Table V. Daily Quantities of 2,4-D Excreted in the Urine and Estimation of Total Dose Received by Each Worker[a]

worker			2,4-D excreted daily (T-1), mg								T-1[b]		2,4-D excreted daily (T-2), mg								T-2[d]	
no.	duty	wt, kg	day 1	day 2	day 3	day 4	day 5	day 6	day 7	day 8	total 2,4-D, mg	2,4-D/ body wt, mg/kg	day 9	day 10	day 11	day 12	day 13	day 14	day 15	day 16	total 2,4-D, mg	2,4-D/ body wt, mg/kg
11	pilot	89.0	nd[c]	nd	nd	nd	0.113	nd	0.048	nd	0.161	0.00179	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
12	mechanic	74.9	nd	nd	0.025	nd	nd	0.008	nd	nd	0.033	0.00044	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
13	batchman	79.5	nd	0.022	0.019	0.120	0.032	nd	nd	nd	0.171	0.00215	nd	nd	0.016	nd	nd	0.026	nd	nd	0.042	0.00053
14	supervisor	97.6	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.037	nd	nd	0.029	0.037	0.00038
15	observer	72.6	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.041	nd	nd	nd	nd	nd	nd	0.041	0.00056
16	observer	72.6	nd	nd	0.040	nd	nd	nd	nd	nd	0.040	0.00055	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
	mean (crew 1)										0.068	0.00082									0.20	0.00024
21	pilot	68.6	0.372	0.445	0.519	0.536	1.156	0.760	0.402	0.446	3.819	0.0557	0.193	0.525	0.389	0.119	0.060	0.339			1.625	0.0237
22	mechanic	95.3	nd	0.189	0.057	0.090	0.074	nd	nd	nd	0.221	0.00232	0.034	0.191	0.109	0.043	0.080	0.035			0.492	0.00516
23	batchman	90.8	0.243	0.253	0.347	0.165	0.554	0.186	0.160	0.306	1.718	0.0189	0.284	0.527	0.354	0.330	0.121	0.163			1.779	0.0196
24	supervisor	102.2	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd			nd	nd
25	observer	84.0	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd			nd	nd
26	observer	72.6	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd			nd	nd
	mean (crew 2)										0.960	0.0128									0.649	0.0081
31	pilot	88.5	nd	nd	0.046	nd	0.063	nd	nd	0.073	0.182	0.00206	0.103	0.042	0.025	nd	nd				0.170	0.00192
32	mechanic	89.9	nd	0.073	0.228	0.434	0.180	0.133	0.148	0.098	1.221	0.0136	0.026	nd	0.083	nd	0.070	0.170			0.349	0.00388
33	batchman	79.5	0.168	0.238	0.542	0.773	0.657	0.337	0.340	0.345	2.994	0.0377	0.261	0.283	0.240	0.306	0.314	0.337			1.741	0.0219
34	supervisor	90.8	nd	nd	0.140	0.152	0.165	0.093	nd	0.078	0.628	0.00692	nd	nd	nd	nd	nd	nd			nd	nd
35	observer	79.5	nd	nd	nd	0.088	nd	nd	nd	nd	0.088	0.0011	nd	nd	nd	nd	nd	nd			nd	nd
36	observer	74.9	nd	nd	0.030	nd	nd	0.064	nd	nd	0.094	0.0013	nd	nd	nd	nd	nd	nd			nd	nd
	mean (crew 3)										0.868	0.0104									0.377	0.0046

[a] Crew 1 = workers 11–16; crew 2 = workers 21–26; crew 3 = workers 31–36. [b] Treatment 1 (T-1) = ordinary precautions. Totals include values from spray day (day 3) plus the next 5 days. [c] nd = not detected; a zero was used for averaging purposes. [d] In treatment 2 (T-2) special precautions were observed. Totals include values from spray day (day 10 for crew 1; day 9 for crews 2 and 3) plus the next 5 days.

Table VI. Comparisons of Respiratory Exposure, Dermal Exposure, and Total Dose of 2,4-D Received during Treatment 1 (T-1) and Treatment 2 (T-2) for Similar-Duty Workers

workers	estimated respiratory exposure, μg/kg T-1	estimated respiratory exposure, μg/kg T-2	estimated dermal exposure, mg/kg T-1	estimated dermal exposure, mg/kg T-2	dose, mg/kg[a] T-1	dose, mg/kg[a] T-2
pilots						
11	nd	nd	nd	nd	0.00179	nd
21	nd	nd	0.0010	nd	0.0557	0.0237
31	nd	nd	0.0007	0.0001	0.00206	0.00192
mean[b]	nd	nd	0.0005	nd	0.0198	0.00854
mechanics						
12	nd	nd	0.0023	0.0005	0.00044	nd
22	nd	nd	0.0059	0.0162	0.00232	0.00516
32	nd	nd	0.0617	0.0006	0.0136	0.00388
mean[b]	nd	nd	0.0233	0.0058	0.00545	0.00301
batchmen						
13	nd	nd	0.0023	0.006	0.00215	0.00053
23	nd	nd	0.0911	0.0216	0.0189	0.0196
33	0.30	nd	0.0409	0.0102	0.0377	0.0219
mean[b]	0.10	nd	0.0448	0.0111	0.0196	0.0140
supervisors						
14	nd	nd	nd	nd	nd	0.00038
24	nd	nd	nd	0.0004	nd	nd
34	nd	nd	0.0005	0.0027	0.00692	nd
mean[b]	nd	nd	0.0002	0.0010	0.00231	0.00013
observers						
15	nd	nd	nd	0.0045	nd	0.0056
16	nd	nd	nd	nd	0.00055	nd
25	nd	nd	nd	nd	nd	nd
26	nd	nd	nd	nd	nd	nd
35	nd	nd	nd	0.0039	0.0011	nd
36	nd	nd	0.0005	nd	0.0013	nd
mean[b]	nd	nd	0.0001	0.0014	0.00049	0.00009

[a] Values include 2,4-D excreted on the spray day plus 5 days following. [b] Where a value of nd (not detected) was obtained, a zero was used for averaging purposes.

multiplying the 2,4-D concentration detected in each sample by the volume of urine in that sample and then summing the values to give a total amount of 2,4-D for each treatment period. When divided by the body weight of the individual involved, the result was an estimate of the 2,4-D dose received over each treatment period. Pharmacokinetic analysis indicated that greater than 95% of the absorbed dose of 2,4-D was excreted in the urine by the end of each treatment period (Ramsey et al., 1980).

Less than 30% of the 524 urine samples analyzed contained levels of 2,4-D above the 0.04-ppm detection limit (Table V). Table VI reveals that most of the positive samples were from the crew members most closely involved with the actual spraying—batchman-loaders, pilots, and mechanics. Thus, there was a relationship between worker duties and levels of 2,4-D detected in the urine. Except for one pilot (worker 21), who had assisted in cleaning spray nozzles, batchman–loaders and mechanics showed the highest levels of 2,4-D in the urine, while observers received the lowest levels. Urine samples from observers standing near the heliport rarely contained any 2,4-D and then in only negligible amounts approaching the limit of detection. The only supervisor excreting 2,4-D (worker 34) was probably exposed when he helped manually transfer the chemical during the T-1 application. Similar exposure did not occur during T-2, and no 2,4-D was detected in his urine in T-2 (Table V).

If one assumes a no-observable-effect level of 24 mg/kg of body weight, as determined from toxicology tests with laboratory animals, then safety factors for the categories of workers involved in this test are substantial (Hall, 1980). At least a thousand times the actual dose received would be necessary to correspond to the toxic levels found to show an effect in the laboratory tests.

Members of crew 1 generally received smaller doses of 2,4-D than did members of the other two crews (Table VI). On the basis of milligrams of 2,4-D per kilogram of body weight over a 6-day period, 2,4-D excretions in urine from crew 1 members ranged from not detectable to 0.00215, while members for crew 2 and crew 3 showed maximum doses of 0.0557 and 0.0377, respectively, for T-1 (Table V). Analysis of variance showed that the amounts of 2,4-D excreted in urine following T-1 were significantly greater ($p \leq 0.014$) than those following T-2. However, when crew 3 was eliminated from the comparisons (because of the different procedure used to transfer the concentrate from the drum to the batch truck), the level of difference between T-1 and T-2 decreased ($p \leq 0.15$).

The differences between T-1 and T-2 might have been greater if all the 2,4-D absorbed during T-1 had been excreted before T-2 began. Nevertheless, if 2,4-D in this study was excreted in a manner similar to the data presented by Sauerhoff et al. (1977), then over 95% of the 2,4-D dose from T-1 would have been excreted in the week prior to initiating T-2.

Five workers in crews 2 and 3, with duties as pilot, mechanics, and batchman–loaders, came into T-1 with low levels of 2,4-D in their urine (Table VI). These findings were confirmed by using two gas chromatographic columns and two different methylating agents. The presence of 2,4-D in the prespray samples was surprising in view of the facts that (1) the worker information sheets filled out by the workers indicated that none of them recalled applying phenoxy herbicides for at least 2 weeks before the study was conducted and (2) human excretion rates for 2,4-D and 2,4,5-T indicated that over 95% of the material absorbed before that time should have been excreted in the 2-week period. Conversations held with these five workers after the study, revealed that they cleaned, assembled, and tested their spray equipment before the study was conducted. Exposure to 2,4-D may have occurred during these activities. Although certain members of crew 1 also performed these tasks, they apparently followed more hygienic practices, since they exhibited little, if any, prespray dose of 2,4-D.

CONCLUSION

This study found that some crew members involved in the aerial application of 2,4-D for forestry purposes absorbed low levels of 2,4-D, but the doses as indicated by urine analyses were several orders of magnitude below the no-observable-effect level determined in toxicology studies. These results are in agreement with those of Nash et al. (1981). The doses were comparable to those found in an earlier test involving aerial application of 2,4,5-T but were substantially lower than those found for ground application of that herbicide (Lavy et al., 1980a).

Nevertheless, this study established that, if desired, exposure to 2,4-D can be reduced by wearing standard protective apparel and following good hygienic practices. This is particularly true for mechanics, batchman–loaders, and pilots, since they are closely involved with the mixing and application of the herbicide. For example, wearing chemically impervious rubber gloves and using modern siphon pumps and drip-free coupling systems on transfer hoses virtually eliminated dermal exposure (the primary route of entry).

Supervisors and observers rarely exhibited any tangible exposure to 2,4-D, even when in close proximity to the spray operation. Those who handled equipment and received detectable doses of 2,4-D did not show levels which would appear to constitute health hazards (Hall, 1980).

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