Exposure to the Herbicide, Paraquat

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The herbicide paraquat has been used extensively during the last few years for control of grasses and certain weeds. It is available to farmers primarily as paraquat dichloride (1,1'-dimethyl-4,4'-bipyridinium dichloride) 29.1% liquid concentrate containing 239.6 grams paraquat cation per liter (2 lbs paraquat cation per gal). For yard and garden spot treatment use it is available in a pressurized dispenser as 0.44% (equivalent to 0.20% paraquat cation) bis(methylsulfate)(1,1'-dimethyl-4,4'-bipyridinium bis(methylsulfate)). Paraquat is of considerable interest because only a very small oral dose of the concentrate may produce irreversible lung fibrosis which often leads to death (BULLIVANT, 1966). Antidotal procedures are not always successful. Although many of the recorded deaths from paraquat have been due to voluntary ingestion with suicidal intent, there have been deaths following accidental ingestion of very small amounts of the liquid concentrate (MALONE et al., 1971). In one case it was estimated that the quantity of concentrate formulation consumed could not have exceeded three-quarters of a teaspoon (approximately 3 ml) MASTERSON and ROCHE, 1971). This compound is also somewhat caustic and may cause chemical damage, thus the possibility of splashing liquid concentrate formulation into the eyes during measuring or mixing the material is of particular concern to applicators. Appropriate warnings in this regard are found on the pesticide label.

In studies of exposure of spray operators to paraquat on Malaysian rubber plantations, SWAN (1969) reported exposure conditions of workers using hand-operated knapsack sprayers which he felt were probably closest to the extremes of exposure likely to occur in any agricultural operation. He was able to find measurable levels of paraquat in the urine of certain workers. The study included periodic medical examinations, including chest radiographs, made before and during exposure and for some weeks afterward. He felt that the investigations indicated that ordinary care in personal hygiene is sufficient to prevent any hazard from surface injury or from systemic absorption of paraquat.

Although the hazard from ingestion of paraquat is well known among applicators in the United States, inquiries received at this

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laboratory from farmers, fieldmen and applicators indicate that, at least in the Pacific Northwest, there is some concern that potential hazard via other routes of entry into the body has not been sufficiently explored. Since the usually fatal disorder involves the lungs, it is understandable that workers might have some fear of the respiratory route of entry of spray droplets during application activities. The product label states that where there is risk of respiratory exposure an approved face mask capable of filtering spray droplets should be worn. MALONE et al. (1971), in reporting a nonfatal paraquat case, felt that renal impairment, which was transient and evidenced only by an elevated BUN and creatinine, resulted from inhalation of dilute spray droplets during application. They felt that, even though CONNING et al. (1969) were unable to produce pulmonary fibrosis in rats using aerosols, in the human it was possible that absorption by inhalation could be sufficiently effective to cause serious problems. KIMBROUGH and GAINES (1970) found that local instillation of 0.05 mg/kg of paraquat into the rat lung caused local fibrosis. In England research with animals exposed to respirable aerosols led GAGE (1968) to suggest that an average concentration of 0.1 mg/M^3 would not be excessive for occupational exposure to "respirable" paraquat aerosols. In this country the threshold limit value of airborne contaminants adopted by the AMERICAN CONFERENCE OF GOVERNMENTAL INDUSTRIAL HYGIENISTS (1973) for paraquat is 0.5 mg/M^3.

The present paper reports results of studies designed to determine the potential exposure of workers in the field operating conventional low-pressure power spray equipment and persons applying paraquat in yard and garden areas using pressurized dispensers. Potential hazard to small children who may handle the pressurized dispensers was also investigated.

MATERIALS AND METHODS

Field exposure tests were performed on workers operating tractor-mounted low-boom spray equipment in orchards. The dosage of herbicide used was 4.677 liters of paraquat dichloride (29.1% liquid concentrate containing 239.6 grams paraquat cation per liter) in 935.3 liters of water per hectare (2 qts paraquat dichloride per 100 gal of water per acre) applied at a pressure of approximately 2.5 kg/cm^2 (35 psi). Exposure tests for yard and garden application were performed on volunteers who, using pressurized hand dispensers, applied 0.44% paraquat (equivalent to 0.20% paraquat cation) as spot application to weeds and grass. Estimation of the amounts of dermal and respiratory exposure that the applicators would potentially incur followed the techniques and procedures described in detail by DURHAM and WOLFE (1962). Potential dermal contamination was measured primarily by attaching absorbent a-cellulose pads to various parts of the worker's body or clothing and allowing them to be exposed during a timed

period of herbicide application operations. Contamination of the hands was measured by rinsing in water in a polyethylene bag. The amount of herbicide entering the body via the respiratory route was estimated from the contamination of special filter pads used in place of the usual outer absorbent filter pads which cover the filter cartridges of the respirators worn by the subjects. The filter pads were covered with inverted plastic funnels modified to a specific aperture size to reproduce as nearly as possible the aerodynamics of air flow through the nostrils. The funnels also prevented direct impingement of droplets or particles onto the pad except for those carried through the apertures by respiratory action. This technique renders it unnecessary to measure total air volume because all inhaled air passes through the filter pads.

Tests to explore the hazard of paraquat to small children who may handle the pressurized dispenser containers designed for yard and garden use were carried out to determine the potential oral exposure that might occur as a result of a child placing a container nozzle in his mouth and either sucking or chewing on the nozzle button or pressing it to cause a discharge of the herbicide into the mouth. A dispenser container nozzle was checked for contamination by removing the container cap or cover and, by inverting the container, placing the nozzle end into a glass jar containing 250 ml of distilled water. The edge of the jar was sealed to the dispenser container with masking tape to prevent leakage and the jar and container were then shaken vigorously for one minute in order to rinse contamination from the nozzle. The rinse samples were analyzed for paraquat content to determine the amount of nozzle contamination available for oral exposure.

Potential oral exposure values for dispenser discharge were obtained by either pressing and releasing the nozzle as quickly as possible or pressing it for a 1-second period, directing the discharge into a glass jar containing 250 ml of distilled water. The pressurized dispenser was held at an angle approximating the position a child would hold it while chewing on the nozzle. The tests involved new full pressurized dispensers, new dispensers that had been "emptied" a short time prior to testing, and older dispensers that were taken at random from a stock that had been partly emptied and stored for 6 months to 3 years.

A total of 230 analyses of dermal and respirator exposure pads and 95 hand rinses was carried out in the present study, representing 35 different paraquat application exposure situations. Exposure pads were extracted in soxhlet extractors, using water acidified with 5 drops of $5N.H_2SO_4$. A total of 130 urine samples was collected from applicators during and following exposure to determine excretion of paraquat as an index of absorption by the body. One-hundred four water samples were analyzed to determine the potential oral exposure of children. The water samples

containing emissions from the pressurized dispensers were first extracted with hexane to remove the oily aliphatic hydrocarbon material. Paraquat analysis was by the method of CHEVRON CHEMICAL CO. (1973) which was based on a procedure outlined by CALDERBANK and YUEN (1965).

RESULTS

Field Exposure: As can be seen in Table 1, potential dermal and respiratory exposure of workers in the field operating conventional low-pressure spray equipment was very low. In 20 different exposure situations studied the highest potential dermal exposure value was only 3.4 mg/hr of application activity (calculated on the basis of the workers wearing short-sleeved, open-necked shirts, no gloves or hats, with clothing worn giving protection of the areas covered). Practically all of the dermal contamination was found on the hands. This is undoubtedly because of hand contact with the liquid concentrate formulation during spray machine loading operations when not wearing protective gloves. Values obtained for respiratory exposure were extremely low. In fact, detectable traces (0.4 to 2.0 μg) of paraquat were found in only four of the respirator filter pad samples. This low exposure potential is probably due not only to the fact that the spray boom nozzles in this type of operation are well below the level of the operator, but also because low-pressure sprayers do not produce many extremely small spray droplets which are more subject to upward drift.

TABLE 1

Potential Dermal and Respiratory Exposure of Spray Applicators to Paraquat[a]

Subject	Route of exposure	Exposure situations studied	Exposure (mg/hr) Range	Mean
Field applicators	dermal	20	0.01- 3.40	0.40
	respiratory	20	el[b]- 0.002	$<$0.001[c]
Yard and garden applicators	dermal	15	0.01- 0.57	0.29
	respiratory	15	el[b]-$<$0.001	$<$0.001[d]

[a]Calculated on the basis of the applicator wearing a short-sleeved open-necked shirt, no gloves or hat, with the clothing worn giving protection of the areas covered.
[b]Below lower limit of sensitivity of the test.
[c]Detectable traces in only 4 samples.
[d]Detectable trace in only 1 sample.

No detectable amounts of paraquat were found in urine samples or field applicators during or following spray operations. The lower limit of detection, based on 50 ml samples, was 0.02 ppm.

Yard and Garden Use: Potential exposure during use of the yard and garden pressurized dispenser was also very low (Table 1). The range of dermal exposure values was much less for yard and garden use (0.01 to 0.57 mg/hr) than for field application (0.01 to 3.40 mg/hr). However, the mean value for yard and garden use (0.29 mg/hr) was only slightly less than that for field use (0.40 mg/hr). As with the field applicators, practically all of the dermal exposure was on the hands. It appeared that most of the hand contamination was due to contact with the discharge at the nozzle. In most exposure situations detectable traces (<0.001 mg/cm^2 of exposed skin area) of paraquat could be found on the lower leg and ankle areas. With the exception of one sample which showed a trace of paraquat (0.8 μg), respiratory exposure values were below the level of the sensitivity of the analytical method. No detectable amounts of paraquat were found in urine samples of the yard and garden applicators (lower limit of detection, 0.02 ppm).

Hazard to Children: Results of tests to determine the potential oral exposure of children who might place their mouths over yard and garden pressurized dispenser nozzles are shown in Table 2. The highest value for nozzle contamination was 0.25 mg of paraquat. It is interesting to note that nozzle contamination

TABLE 2

Potential Oral Exposure of Children to Paraquat Resulting from Mouth Contact with Contaminated Pressurized Dispenser Nozzle or from Nozzle Discharge into Mouth

Container		Potential Exposure (mg)[a] Nozzle contamination	Brief discharge[b]	1-sec. discharge
New full dispensers	Range	NA[c]	0.05-0.53	0.11-1.74
	Mean		0.30	1.11
New "emptied" dispensers	Range	0.01-0.21	0.01-0.16	0.01-0.54
	Mean	0.07	0.04	0.14
Old partly-used dispensers	Range	el[d]-0.25	el[d]-0.18	0.01-0.05
	Mean	0.08	0.03	0.02

[a]Total of 104 tests (from 9 to 16 replicates of each).
[b]Sharply pressing the dispenser nozzle and releasing it as quickly as possible.
[c]Not applicable.
[d]Below lower limit of sensitivity of test.

values were as high for old partly-used dispensers as for new dispensers immediately after being emptied. The highest value for a brief nozzle discharge was 0.53 mg and for the 1-second discharge the highest value was 1.74 mg of paraquat. As was expected, new full dispensers produced higher discharge values than did the new "emptied" or old partly-used dispensers. Even though the values for the "emptied" containers are lower, they do indicate that such containers are not always completely empty and thus can be a potential hazard to small children.

DISCUSSION

Results of the above studies on dermal and respiratory exposure to paraquat indicate that hazard to both field applicators and persons using the yard and garden pressurized dispenser is minimal when used under the conditions described. If the 80 mg/kg acute dermal LD_{50} value obtained for male white rats (KIMBROUGH and GAINES, 1970) is used in calculation, the approximately 3.4 mg/hr combined maximum potential dermal-respiratory exposure obtained would represent only 0.06% of a toxic dose per hour of exposure.

The inability to detect paraquat in the urine during and following exposure in this study indicated that absorption of the herbicide was minimal. However, these findings should not detract from the need to be concerned about ingestion of even small amounts of the concentrated formulations, inasmuch as accidental ingestion has resulted in illness and death. The storage of the herbicide in soft drink bottles, or any container that is not the original properly-labeled container, presents one of the greatest hazards, especially to small children who may accidentally drink the material.

In consideration of the fact that the greatest exposure was found to be on the hands, label recommendations concerning the use of protective gloves should be followed. None of the applicators studied had open cuts on their hands; therefore, we feel that the possibility of increased absorption via this route has not been clarified. Because of the caustic nature of paraquat, special effort should be made to prevent skin contact, especially with the concentrate formulation used in field applications. It is of particular importance to prevent splashing the material into the eyes or mouth. If such contamination does occur, flush the eyes or mouth thoroughly with water and report to a physician. Any skin area contaminated with the concentrate formulation should be immediately washed.

It is difficult to estimate the potential hazard of the yard and garden pressurized dispenser to young children with any great degree of accuracy. A one-second discharge from the container yielded a maximum value of 1.74 mg of paraquat (with an average of 1.11 mg). If the 100 mg/kg acute oral LD_{50} value obtained for

male white rats (KIMBROUGH and GAINES, 1970) is used in calculations, the 1.74 mg maximum potential amount available for ingestion would represent only 0.14% of a toxic dose for a 12.3 kg (27 lb) child. However, a point to consider is that toxicity studies on rats may not accurately reflect the hazard to human beings because of delayed pulmonary changes resulting from ingestion of small amounts of paraquat. Nevertheless, at such low doses there is still considerable margin of safety even if man is more sensitive than the rat. In estimating hazard to children the mildly caustic nature of the formulation and the content of the aliphatic petroleum solvent (15%) must be considered as well as the toxicity of the paraquat.

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