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Fayetteville, North Carolina

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PREFACE

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ACKNOWLEDGMENTS AND AVAILABILITY OF REPORT

This report was prepared by Steven W. Lenhart, CIH, of the Hazard Evaluations and Technical Assistance Branch, Division of Surveillance, Hazard Evaluations and Field Studies (DSHEFS). Desktop publishing by Caren B. Day and Ellen E. Blythe.

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SUMMARY

Air sampling was conducted during spray applications of paraquat in response to a request for a health hazard evaluation (HHE) from the Director of the U.S. Department of Agriculture's (USDA) witchweed eradication program. USDA's witchweed eradication program started in 1957 with a goal of eradicating witchweed from eastern North Carolina and South Carolina, the only location in the western hemisphere where witchweed is known to occur. Witchweed is a parasitic annual that can attack and severely damage corn, sorghum, sugarcane, dryland rice, and more than 60 other grasses. Because of paraquat's toxicity, the variety of application methods used to apply this herbicide, and heat stress issues, an HHE was requested so that decisions about when respirators needed to be worn and what kind of respirators should be worn could be based upon air sampling results. The concern of the HHE's requestor was that applicators would be reluctant to comply with a requirement to wear a respirator and endure the concurrent heat-stress burden without evidence supporting a need for respiratory protection.

Air samples for both total and respirable paraquat were collected during eight paraquat applications. Spray applications lasting from 14 to 144 minutes were made using hand-operated knapsack sprayers and all-terrain vehicles, farm tractors, and high-cycle tractors with attached spray booms. All air samples were collected in the breathing zone of each pesticide applicator. Paraquat was not detected on any of the air samples.

The results of this HHE suggest that pesticide applicators have essentially no risk for inhalation exposure to paraquat during witchweed eradication activities. Consequently, wearing a respirator during these activities is unnecessary and may have an adverse effect of contributing to an applicator's heat-stress burden. However, paraquat is also an eye and skin irritant and a serious ingestion hazard, and a potential existed for spills and splashes during mixing, loading, and maintenance activities and for eye and hand exposures during knapsack applications. Since personal protective equipment was seldom used by the pesticide applicators who participated in this study, risks for paraquat exposures did exist. Recommendations are given concerning the personal protective equipment that should be worn during witchweed eradication activities.

Keywords: SIC 9199 (general government), agriculture, Gramoxone®, herbicide, pesticide, paraquat dichloride (1,1'-dimethyl-4,4'-bipyridinium dichloride), respirators, witchweed.

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INTRODUCTION

An industrial hygienist from the National Institute for Occupational Safety and Health (NIOSH) conducted air sampling during spray applications of the contact herbicide paraquat dichloride (1,1'-dimethyl-4,4'-bipyridinium dichloride). Air sampling was conducted in response to a request for a health hazard evaluation (HHE) from the Director of the U.S. Department of Agriculture's (USDA) Witchweed Eradication Program in Fayetteville, North Carolina. Plant Protection and Quarantine (PPQ) officers of USDA's Animal and Plant Health Inspection Service and USDA's contract pesticide applicators are potentially at risk for inhalation, skin, and eye exposures to paraquat when using knapsack sprayers and driving all-terrain vehicles, farm tractors, and high-cycle tractors with attached spray booms. A risk for inhalation, skin, and eye exposures also occur while mixing and loading pesticides and repairing pesticide-contaminated equipment. Because of paraquat's toxicity and the variety of application methods used by PPQ officers and USDA contract applicators, an HHE was requested so that decisions about when respirators needed to be worn and what kind of respirators should be worn could be based upon air sampling results.

Gramoxone® Extra was the paraquat-containing herbicide applied during the NIOSH air sampling survey. This product is a restricted use pesticide and contains 37% paraquat dichloride (2.5 pounds of paraquat cation per gallon) and 63% inert ingredients.[1] Gramoxone ® Extra also contains a stenching agent to give it an odor and an emetic agent to cause vomiting in anyone who accidentally or intentionally ingests some of the chemical. Clean water is always used as the spray carrier when a diluted solution is mixed before an application.

BACKGROUND

Witchweed (*Striga asiateca*) is an obligate parasitic annual that can attack and severely damage corn, sorghum, sugarcane, dryland rice, and more than 60 other gramineous species (grasses).[2] Witchweed and related Striga species are considered among the most serious crop pests of Africa, the Middle East, and Far East countries in thwarting cereal crop production. Witchweed does its damage when its tiny seeds germinate and penetrate the roots of host plants, robbing them of necessary water and nutrients.[3] Parasitized plants are usually stunted, and heavy infestations will kill the crop.

USDA's witchweed eradication program started in 1957 with a goal of eradicating witchweed from eastern North Carolina and South Carolina, the only location in the western hemisphere where witchweed is known to occur. One component of the Witchweed Eradication Program is the use of contact herbicides to treat infested fields, gardens, idle parcels of land, and areas where grass and weeds are present in non-host crops such as cotton, peanuts, and soybeans.

EVALUATION CRITERIA

General Guidelines

To assess the health hazards posed by workplace exposures, NIOSH investigators use a variety of environmental evaluation criteria. These criteria suggest exposure levels to which most workers may be exposed for a working lifetime without experiencing adverse health effects. However, because of wide variation in individual susceptibility, some workers may experience occupational illness even if exposures are maintained below these limits. The evaluation criteria do not take into account individual hypersensitivity, pre-existing medical conditions, or possible interactions with other workplace agents, medications being taken by the worker, or environmental conditions. Evaluation criteria typically change when new information on the toxic effects of an agent become available.

The primary sources of evaluation criteria for the workplace are NIOSH criteria documents and recommended exposure limits (RELs),[4] the American Conference of Governmental Industrial Hygienists (ACGIH) threshold limit values (TLVs),[5] and the Occupational Safety and Health Administration (OSHA) permissible exposure limits (PELs).[6] These values are usually based on a time-weighted average (TWA) exposure, which refers to the average airborne concentration of a substance over an entire 8- to 10-hour workday. Concentrations are usually expressed in parts per million (ppm), milligrams per cubic meter (mg/m^3), or micrograms per cubic meter ($\mu g/m^3$). In addition, some substances have only a ceiling limit, a concentration that should not be exceeded during any part of a workday.

Other substances have a short-term exposure limit (STEL) to supplement a TWA limit where there are recognized toxic effects from short-term exposures. A STEL is a 15-minute TWA concentration which should not be exceeded at any time during a workday even if the 8-hour TWA is less than the exposure limit. The ACGIH recommendation for a substance without a STEL is that "excursions in worker exposure levels may exceed 3 times the TLV-TWA for no more than a total of 30 minutes during a workday, and under no circumstances should they exceed 5 times the TLV-TWA, provided that the TLV-TWA is not exceeded."[5] The basic concept is that excursions above a substance's 8-hour TWA exposure limit should be maintained within reasonable limits in well-controlled processes. Additionally, some chemicals have a skin notation to indicate that the substance may be absorbed through direct contact of the material with the skin and mucous membranes.

NIOSH RELs are based primarily on the prevention of occupational disease. In contrast, OSHA PELs and other OSHA standards are required to take into account the economic feasibility of reducing exposures in affected industries, public notice and comment, and judicial review. In evaluating worker exposure levels and NIOSH recommendations for reducing exposures, it should be noted that employers are legally required to meet OSHA standards.

An additional complication is that a Court of Appeals decision vacated the OSHA 1989 Air Contaminants Standard in AFL-CIO v OSHA, 965F.2d 962 (11th cir., 1992); OSHA now enforces the previous 1971 standards.[6] However, some states which have OSHA-approved state plans will continue to enforce the more protective 1989 OSHA PELs. NIOSH encourages employers to use the 1989 OSHA PELs or the NIOSH RELs, whichever are lower.

Paraquat dichloride

Paraquat dichloride (CAS number 1910-42-5) is a contact herbicide used to control or suppress a broad spectrum of emerged weeds and is also used as a crop desiccant at harvest.[1] Paraquat is non-volatile with an essentially negligible vapor pressure of <0.0000001 millimeter of mercury at 68° F.[7] It occurs as colorless and odorless crystals and is marketed as aqueous solutions containing surfactants.[8] Paraquat is an irritant of the eyes, mucous membranes, and skin; ingestion causes fibroblastic proliferation in the lungs.[9] However, there is no evidence that inhalation exposures in occupational settings cause the rapid progressive pulmonary fibrosis and injury to the heart, liver, and kidneys that occurs from ingestion.[9] Paraquat's toxicity in the lung is apparently dependent on the size of inhaled particles. Respirable particles (i.e., particles with mass median diameters less than 5 micrometers) have been reported to be from five to six times more toxic than nonrespirable particles.[8]

Eye exposure to paraquat concentrate can cause corneal and conjunctival inflammation. The inflammation develops gradually and can progress to maximum damage from 12 to 24 hours after exposure. The seriousness of an eye injury following paraquat exposure may be relatively unnoticeable until the damage has progressed to corneal scarring.[10]

Most herbicide poisonings are due to unintentional spillage or intentional ingestion.[11] The consequences of ingesting paraquat are in marked contrast to the irritant effects usually encountered with occupational exposures; there are numerous reports of fatal accidental and suicidal ingestions by humans.[9] The prognosis for paraquat toxicosis is generally grave, and there is no specific antidote. Effective treatment for paraquat poisoning depends upon rapid gastrointestinal emptying to prevent excessive absorption.[11] Death from paraquat ingestion is caused primarily by progressive pulmonary fibrosis that leads to respiratory failure.[12] There have been deaths following accidental ingestion of very small amounts of liquid concentrates containing 29% paraquat, and in one case the quantity of liquid concentrate consumed was reported to have been not more than three-quarters of a teaspoon (approximately 3 ml).[13] Researchers found that paraquat caused more deaths in Costa Rica than any other pesticide regardless of the cause of poisoning (53% of suicides, 77% of non-occupational accidents, and 86% of occupational accidents).[14] In the same study, paraquat was identified as the causative agent in 24% (516 of 2178) of hospitalizations resulting from pesticide poisonings.

The NIOSH REL and the ACGIH TLV for respirable paraquat are both an 8-hour TWA of 100 $\mu g/m^3$.[4, 5] ACGIH has also recommended a TLV-TWA of 500 $\mu g/m^3$ for total paraquat based on nonrespirable particles being five to six times less toxic than respirable particles.[8] The NIOSH REL has a skin notation; the ACGIH TLV does not. After a literature review in 1978, ACGIH deleted their skin notation because of a lack of evidence suggesting that systemic toxicity resulted from dermal absorption of paraquat.[8] The OSHA PEL is an 8-hour TWA of 500 $\mu g/m^3$ for respirable paraquat with a skin notation.[6] The NIOSH immediately dangerous to life or health (IDLH) air concentration for paraquat is 1,000 $\mu g/m^3$.[7] Researchers conducted a laboratory study to assess the mutagenic potential of Gramoxone® (a formulation of 20% paraquat) at the gene and chromosomal levels using a battery of five different eukaryotic systems. Their results demonstrated mutagenicity in all bioassay systems tested, and they concluded that paraquat should be regarded a mutagenic herbicide.[15]

Section 170.240 of the EPA worker protection standard requires that "any person who performs tasks as a pesticide handler shall use the clothing and personal protective equipment specified on the labeling for use of the product."[16] Generic personal protective equipment and work clothing requirements for pesticide handling activities are given in Table 1 of section 156.212 (d) of the EPA labeling requirements for pesticides and devices.[17] The minimum personal protective equipment and work clothing requirements are specified by EPA according to the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) category of a pesticide formulation's active ingredient. FIFRA categories are equivalent to toxicity ratings ranging from extremely toxic (category I, signal word: danger) to practically nontoxic (category IV, signal word: caution).[18]

All paraquat-containing herbicides and desiccants are FIFRA category I pesticides.[19] According to the label for Gramoxone® Extra, an applicator of this herbicide must wear coveralls over a long-sleeved shirt and long pants, waterproof gloves, chemical-resistant footwear plus socks, protective eyewear, chemical-resistant headgear for overhead exposure, a chemical-resistant apron when cleaning equipment, mixing, or loading, and a dust and mist filtering respirator (NIOSH approval number prefix TC-21C).[1] These personal protective equipment and work clothing requirements can be downgraded for pesticide applicators who use enclosed systems to mix or load pesticides, or if they apply pesticides when they are inside enclosed tractor cabs or in airplane cockpits.[16]

METHODS

Air samples for both total and respirable paraquat were collected during spraying applications. Each air sample was collected in the breathing zone of a pesticide applicator by attaching one of the samplers to each lapel of the applicator's shirt. Equipment for each total paraquat sample consisted of a closed-face, two-piece, 37-millimeter (mm) cassette containing a 1-micrometer (µm) pore size, Teflon™ filter and a supporting pad. Each cassette was connected by flexible tubing to a personal sampling pump operated at a flow rate of 2.0 liters per minute (L/min).

Equipment for each respirable paraquat sample consisted of a 10-mm, Dorr-Oliver nylon cyclone connected by flexible tubing to a personal sampling pump operated at the required flow rate of 1.7 L/min. Respirable particles separated by the cyclone were collected on a 1-µm pore size, Teflon™ filter in a closed-face, two-piece, 37-mm cassette. Field blanks were submitted for each day of air sampling. All air samples and field blanks were analyzed for paraquat according to NIOSH analytical method 5003.[20]

RESULTS

Air sampling was conducted on September 27–29, 1994, during eight paraquat applications in the vicinity of Lumberton, North Carolina. The weather on these three days was clear and sunny. Temperatures were warm, ranging from 80° to 90° F during the application periods. Relative humidities ranging from 15% to 60% were measured, and winds were light. Applications lasting from 14 to 144 minutes were made using hand-operated knapsack sprayers and all-terrain vehicles, farm tractors, and high-cycle tractors with attached spray booms. During four applications, 2,4-D (Weedar® 64 or Weed RHAP® A-4D) was applied with paraquat, and during one application, glyphosate isopropyl ammonium (Roundup®) was also applied. Air samples were not collected for either of these postemergence herbicides.

According to the product label, an application rate of 1.5 pints of Gramoxone® Extra per acre is recommended for postemergence directed spraying and USDA witchweed eradication program activities.[1] This application rate, equivalent to 0.5 pound of paraquat cation per acre, is prepared by mixing a water-diluted solution with a strength of 0.5% (ratio of the weight of active ingredient to the weight of the spray carrier). A strength of 0.5% (w/w) can also be described as a 1:60 dilution (v/v) of Gramoxone® Extra. During this survey for example, 0.5% strength paraquat solutions were mixed for tractor applications using 2 gallons of Gramoxone® Extra (5 pounds of paraquat cation) and 120 gallons (1,000 pounds) of water. Regardless of the application method used, all of the solution strengths prepared during this survey were 0.5% or less.

The eight sampled paraquat applications were made by three PPQ officers and two USDA contractors. All of the applicators wore long pants, work boots, and socks. Three wore short-sleeved shirts, and two wore long-sleeved shirts. Three applicators wore baseball caps, one wore a plastic pith-style helmet, and one did not wear a hat. One of the knapsack applicators wore reusable rubber gloves and boots during pesticide-mixing activities and applications. None of the other applicators wore any type of gloves or chemical-resistant footwear at any time during the days of the air sampling survey. Also, none of the applicators wore coveralls; protective eyewear; a chemical-resistant apron when cleaning equipment, mixing, or loading; or a NIOSH-approved dust and mist filtering respirator, even though the pesticide's label clearly specified the use of all these items.

Application locations, activities sampled, application rates, sample numbers, sampling durations, and air sampling results are presented in Table 1. Paraquat was not detected on any of the samples. The analytical limit of detection for this set of air samples was 20 µg per sample, and the analytical limit of quantitation was 34 µg per sample. Using the analytical limit of detection, the minimum detectable air concentrations for total paraquat ranged from 70 µg/m^3 (an air sample with a duration of 144 minutes) to 700 µg/m^3 (an air sample with a duration of 14 minutes). The minimum detectable air concentrations for respirable paraquat ranged from 80 µg/m^3 (an air sample with a duration of 144 minutes) to 830 µg/m^3 (an air sample with a duration of 14 minutes).

Discussion and Conclusions

Section 170.202 (b) of EPA's worker protection standard describes nine exceptions to which Subpart C–Standard for Pesticide Handlers does not apply.[16] Situations for which this subpart does not apply include wide-area public pest control programs sponsored by government entities. Therefore, regardless of the minimum personal protective equipment and work clothing specified on a pesticide's label, PPQ officers and USDA contractors are not legally bound to use them.

This HHE was requested to establish, based on air sampling measurements, when respirators needed to be worn during paraquat applications. Herbicides are applied as part of the Witchweed Eradication Program during the warmest months of the year in North Carolina and South Carolina after witchweed seeds have germinated and plants have emerged. Heat stress is a recognized health hazard associated with these applications. A concern of the HHE's requestor was that applicators would be reluctant to comply with a requirement to wear a respirator and endure the concurrent heat-stress burden without evidence supporting a need for respiratory protection. Also, the HHE requestor asked for guidance about how to select an appropriate respirator when a pesticide's label indicates only that unspecified respiratory protection should be worn during an application.

Concerning the use of personal protective equipment other than respirators, a judgement had been made that the risk of experiencing heat-stress related illnesses exceeded in importance the risk for experiencing pesticide-related illnesses. Consequently, PPQ officers and USDA contractors were not required by their supervisors to wear any of the personal protective equipment or work clothing described on the Gramoxone® Extra label. EPA acknowledges that the use of personal protective equipment by pesticide handlers and early-entry workers "can present a conflict between protection against pesticide exposure and avoiding heat stress."[21] However, information in EPA's *Guide to Heat Stress in Agriculture* suggests measures that can be taken that will allow such workers to wear required personal protective equipment and still avoid heat illness.[21]

The relatively high minimum detectable air concentrations for both total and respirable paraquat samples collected during the 14-minute knapsack application demonstrate a limitation of NIOSH analytical method 5003 for evaluating health risks associated with short-term applications. Nevertheless, the overall results of this air sampling survey suggest that PPQ officers and USDA contractors have essentially no risk for inhalation exposure to paraquat during witchweed eradication activities. Consequently, wearing a respirator during these activities is unnecessary and may have an adverse effect of contributing to an applicator's heat-stress burden.

When compared to ingestion and skin exposure, pesticide inhalation during outdoor agricultural applications is generally considered a negligible contributor to total body burden.[22] Findings have been published by researchers who evaluated paraquat applications using knapsack sprayers that lasted for several hours a day.[23–25] The authors of these studies also concluded that there is essentially no inhalation exposure to paraquat associated with this application method. A similar conclusion was made by a researcher who evaluated inhalation exposures of workers operating tractor-mounted low-boom spray equipment in orchards.[13]

One explanation for the low inhalation health risk associated with spray applications of paraquat is that the droplets created by the nozzles of the knapsack sprayers and on the booms are so large that they settle quickly and therefore remain aerosolized for only a short period of time.[13, 24, 26, 27] Any remaining risk is further reduced because of paraquat's non-volatility. The likelihood that aerosol drift could be created during an application is reduced as a result of a witchweed program operating procedure of applying paraquat only on days when winds are calm. However, risks of paraquat exposures did exist because (1) paraquat is also an eye and skin irritant and a serious ingestion hazard, (2) a potential existed for spills and splashes during mixing, loading, and maintenance activities, (3) a potential existed for eye and hand exposures during knapsack applications,[23–25, 28] and (4) personal protective equipment was seldom used by the pesticide applicators who participated in this study.

As described earlier in this report, EPA's generic personal protective equipment and work clothing requirements for pesticide handling are based solely on the relative toxicities of individual pesticides. In the preamble to the final worker protection standard, EPA commented that they did not consider other factors, such as the type of pesticide formulation, pesticide use patterns (e.g., application method and measured exposure levels), or modes of action, when developing their personal protective equipment and work clothing requirements.[16] By not considering any other factors but toxicity, EPA created the potential of requiring the use of personal protective equipment at times when it was actually unnecessary. Regarding respirator use for example, air sampling measurements suggested that complying with EPA's requirement that a respirator be used solely because paraquat is a FIFRA category I pesticide was unnecessary for the application conditions evaluated. More importantly from the standpoint of protecting the health of a pesticide applicator, EPA's approach also creates the potential of not requiring the use of specific personal protective equipment when it is necessary. These problems are most likely to occur when EPA's personal protective equipment and work clothing requirements are either not specific enough, or when they are inadequate.

The respirator requirement listed on the Gramoxone® Extra label is an example of a requirement that is not specific enough. The label's respirator requirement is "dust/mist filtering respirator (MSHA/NIOSH approval number prefix TC-21C)." The label's respirator requirement was perceived by USDA employees to be too general because several different respirators with varying levels of protection meet this general description. Dust and mist filtering respirators include filtering-facepiece disposable respirators; elastomeric quarter-mask, half-mask, and full-facepiece respirators with replaceable cartridges; and powered air-purifying respirators with half-masks, full-facepieces, loose-fitting facepieces, hoods, or helmets.

The other important issue associated with EPA's generic personal protective equipment requirements is that a label's respirator requirement may be inadequate for protecting a pesticide applicator from possible inhalation overexposure. Such situations are especially likely to occur with applications of FIFRA category III or IV pesticides. While EPA requires respirator use during applications of a FIFRA category I or II pesticide, respirators are not required during applications of a FIFRA category III or IV pesticide.[15] While this issue may not be important for most outdoor pesticide applications, it is of particular concern for applications of FIFRA category III and IV pesticides inside greenhouses. For example, air concentrations of diazinon, a FIFRA category III insecticide with an 8-hour TWA occupational exposure limit of 100 $\mu g/m^3$,[4, 5] were measured during and after a coldfogging application in a greenhouse.[29, 30] Four-hour TWA air concentrations of diazinon measured during the application ranged from 730 to 3,030 $\mu g/m^3$. Eight-hour TWA air concentrations measured during the next work shift following the expiration of the EPA restricted entry interval ranged from 70 to 250 $\mu g/m^3$; residual air concentrations of diazinon persisted for several days afterward.[29, 30]

The preceding example reveals a shortcoming in EPA's approach of basing personal protective equipment and work clothing selection solely on a pesticide's toxicity and ignoring actual exposures that occur during pesticide applications. For most occupational situations, establishing the need for protecting workers from potentially harmful exposures or selecting appropriate personal protective equipment for workers to use is determined after making exposure measurements of a contaminant. Respirator selection is a good example of how this process works.[31, 32]

Because respirators provide different levels of protection, they have been divided into classes, and each respirator class has been given an assigned protection factor to help distinguish their protective capabilities. The assigned protection factors of respirators range from 5 to 10,000.[31, 32] Quarter-mask respirators and most disposable respirators represent the low end of this range, and self-contained breathing apparatuses operated in pressure-demand modes represent the high end. Between these two assigned protection factors are a variety of negative-pressure, powered air-purifying, and atmosphere-supplying respirators that are available with half masks, full facepieces, loose-fitting facepieces, hoods, or helmets.

A minimum level of respiratory protection needed for a given situation is calculated by dividing the highest exposure measurement of a contaminant by its most protective occupational exposure limit. Then, a respirator from the class of respiratory protection with an assigned protection factor equal to or exceeding the minimum level of protection is selected for use. For example, assume that the data presented previously for a 4-hour coldfogging application of diazinon were also accurate estimates of 8-hour TWA exposures. Dividing 3,030 $\mu g/m^3$, the highest diazinon air concentration measured, by diazinon's occupational exposure limit of 100 $\mu g/m^3$, equals 30. Consequently, a respirator with an assigned protection factor of at least 30 would be selected for use. According to the *NIOSH Respirator Decision Logic*, this needed minimum level of respiratory protection eliminates from consideration negative-pressure quarter-mask and half-mask respirators (disposables and elastomerics), negative-pressure full facepiece respirators with non high-efficiency filters, demand half-mask supplied-air respirators, powered air-purifying respirators with loose-fitting facepieces, and continuous flow supplied-air respirators with hoods or helmets.[31] Appropriate respirators, those with assigned protection factors greater than 30, include negative-pressure full facepiece respirators with high-efficiency filters, powered air-purifying respirators with tight-fitting facepieces and high-efficiency filters, and self-contained breathing apparatuses.

RECOMMENDATIONS

The following recommendations will reduce the exposure risks associated with herbicide applications conducted as part of the Witchweed Eradication Program. Although air samples were collected for only paraquat, implementation of these recommendations will also protect applicators from exposures to the other herbicides used during this survey.

- All PPQ officers and USDA contractors should understand the health risks associated with paraquat exposure, especially the specific life-threatening danger associated with ingestion of very small amounts of the concentrate. Also, the health risks of other pesticides used in the Witchweed Eradication Program (e.g., 2,4-D and glyphosate isopropyl ammonium) should be understood.

- If the need occurs again to select respiratory protection for applications of a pesticide other than paraquat, the selection process should be based on air sampling measurements, the most protective occupational exposure limit of the pesticide, and assigned protection factors for the various respirator classes.

- Precautions should be taken to reduce the risk of acute exposures to paraquat during mixing, loading, and maintenance activities. During these activities, a full facepiece shield should be worn to protect the eyes, face, and mouth from spills and splashes. Skin exposures – and especially hand exposures – are generally considered the major exposure route of pesticides during mixing, loading, and application.[33, 34] To protect against skin exposures during mixing, loading, and maintenance activities, a chemical-resistant apron, disposable sleeve protectors, and chemical-resistant gloves should be worn. When selecting chemical-resistant gloves, disposable gloves should be considered instead of reusable gloves, which need to be decontaminated after each use. Disposable nitrile, latex, vinyl, and polyethylene gloves are available in several different sizes. Of these four materials, nitrile gloves and polyvinyl alcohol gloves showed the longest breakthrough times when tested against agricultural pesticides.[35] A disadvantage of latex gloves is that some people have an allergic reaction to this material.[36–39] Regardless of the glove material selected, a common complaint of users of chemical-resistant gloves is that the gloves are uncomfortable because they cause their hands to perspire. To reduce this discomfort, light-weight inspector's gloves can be worn under chemical-resistant gloves to absorb perspiration.

- During knapsack applications of paraquat, use of a full facepiece shield should be required to protect an applicator's eyes, face, and mouth, and use of chemical-resistant gloves (disposable or reusable) should be required to protect an applicator's hands.

- Knapsack sprayers with leaking nozzles or leaks at joints should be repaired before their next use.

- During paraquat applications using all-terrain vehicles or tractors, no specific personal protective equipment is needed, but personal protective equipment should be available in case an applicator needs to repair application equipment in the field.

- An extra set of clean clothing and shoes should be stored in each applicator's vehicle to wear in case his or her clothes get wet from a spill, splash, or leaking knapsack sprayer.

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Table 1
Air Concentrations of Paraquat Measured During Spray Applications
U.S. Department of Agriculture
Animal and Plant Health Inspection Service
Plant Protection and Quarantine
Fayetteville, North Carolina
HETA 94-0413-2560

Application Equipment	Location	Activity Sampled	Paraquat Application Rate (pound/acre)	Air Sample Type and Number	Sampling Duration (min)	Paraquat Air Concentration (mg/m^3)
Knapsack Sprayer	Grassy Garden	Application	0.5	R-02 T-52	14 14	ND ND
Knapsack Sprayer	Grassy Garden	Mixing and Application	0.5	R-09 T-59	32 32	ND ND
All-Terrain Vehicle (7-No.3 Nozzles)	Grassy Garden	Application	0.5	R-01 T-51	28 28	ND ND
All-Terrain Vehicle (7-No.3 Nozzles)	Beside a Grassy Drainage Ditch	Application	0.25	R-07 T-57	24 24	ND ND
Farm Tractor without a Cab (25-No.2 Nozzles)	Grassy Harvested Corn Field	Mixing	0.38	R-03 T-53	36 36	ND ND
		Application		R-04 T-54	30 30	ND ND
Farm Tractor without a Cab (25-No.2 Nozzles)	Idle Land	Mixing and Application	0.5	R-10 T-60	144 144	ND ND
High-cycle Tractor with Enclosed Cab (9-No.3 Nozzles)	Idle Land	Mixing and Application	0.5	R-05 T-55	53 53	ND ND
High-cycle Tractor without a Cab (17-No.3 Nozzles)	Grassy Harvested Corn Field	Mixing and Application	0.25	R-08 T-58	100 100	ND ND

R: Respirable sample collected using a 10-mm Dorr-Oliver cyclone at a flow rate of 1.7 liters per minute.
T: Total sample collected using a 37-mm cassette at flow rate of 2 liters per minute.
ND: None detected.