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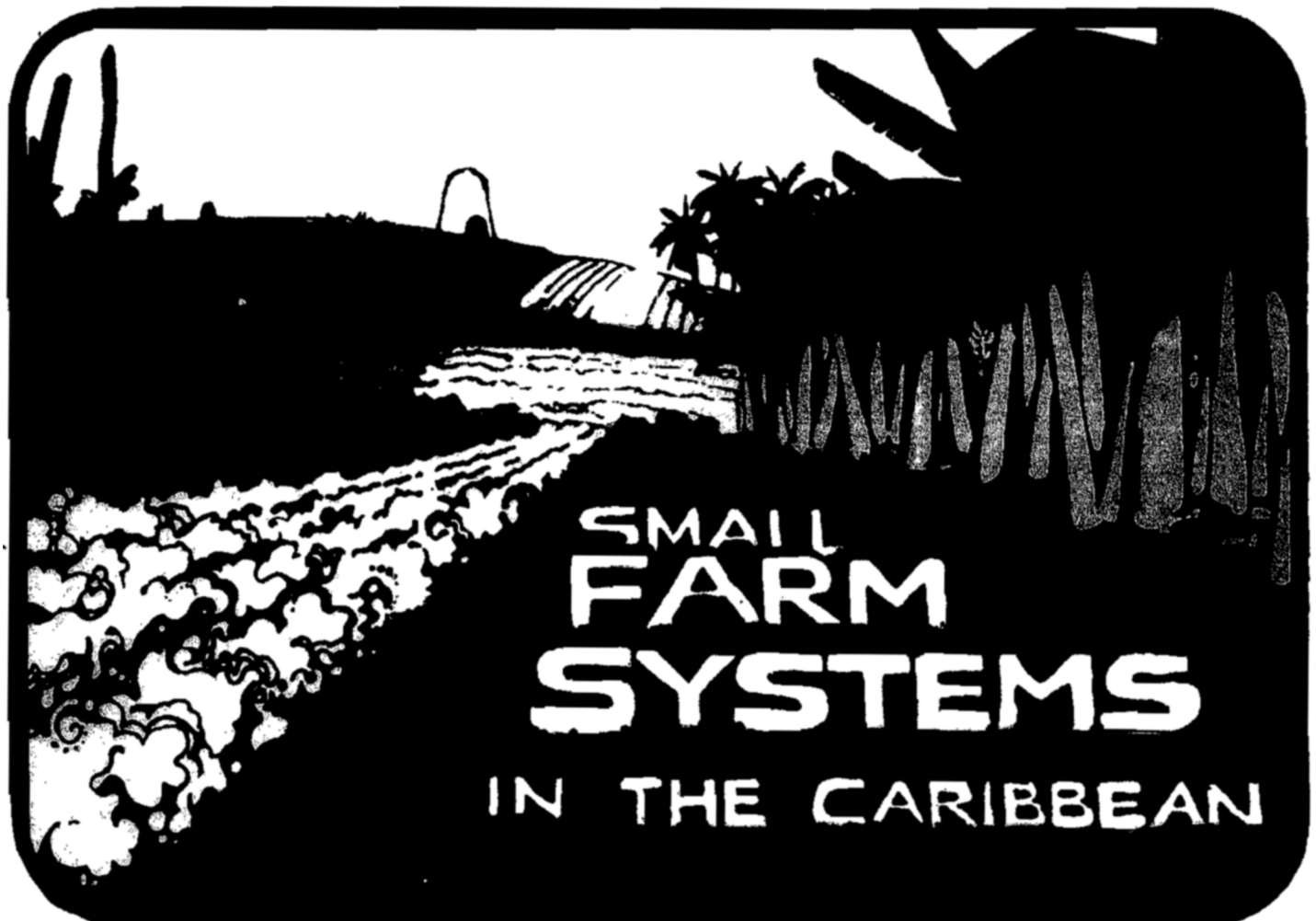
SMALL FARM SYSTEMS IN THE CARIBBEAN

Exposure of Farm Labor to Pesticides

H. N. Nigg   **J. H. Stamper**

University of Florida
Citrus Research and Education Center
700 Experiment Station Road
Lake Alfred, FL 33850, USA

The purpose of this article is to review agricultural pesticide monitoring methods and suggest ways to protect farm labor from unnecessary exposure. A comparison of pesticide exposure for various application methods indicates exposure in the order, airblast > high-boy ≥ low-boy > hand application. Anatomical regions of the body receive total exposure in the order, hands > legs ≥ arms > chest > head, with the back and buttocks generally receiving lower exposure. Urinary metabolite and blood acetylcholinesterase methods are generally not definitive for monitoring exposure except in acute poisoning cases. Possible protective methods suggested by these exposure studies are outlined, with particular reference to small farm use.

Keywords: Fieldworker; exposure; pesticides; methods.

The assessment and minimization of farmworker exposure to pesticides has been a research effort since the introduction of organic pesticides in the late 1940's. Research concentrates on two groups:

1. agricultural harvester exposure to residual pesticides, and
2. pesticide exposure of workers mixing, loading, and applying pesticides.

Each of these work activities involves special circumstances and dangers. The small acreage farmer may encounter hazards faced by both groups.

Methods for monitoring the exposure of farmworkers to pesticides were reviewed by Davis (1980). The purpose of this report is to update and expand that review, discuss problems relating to pesticide monitoring procedures, and suggest possible protective methods which small acreage farmers might employ.

Applicator Exposure Methods

Applicator exposure studies have usually monitored dermal exposure, cholinesterase levels, and urinary metabolites for the human applicator, often in conjunction with more intrusive animal experiments. One of the first applicator studies was by Kay et al. (1952) who measured cholinesterase levels in orchard parathion applicators. They compared these with cholinesterase levels from non-spray periods. Plasma cholinesterase was 16% lower for sprayers reporting physical symptoms and this value was 20% lower than the no-symptom group. Erythrocyte cholinesterase was depressed 27% for the symptom group vs. 17% for the non-symptom group, but these means were not statistically different. In 1958 Quinby et al. measured cholinesterase activity in aerial applicators as well as residues collected on worker clothing and respirator pads. Despite physical complaints by pilots exposed to organophosphates, their investigation revealed either normal or only slightly depressed cholinesterase levels. However, these cholinesterase levels were compared with the "normal" range for the U.S. population rather than the pilots' individual "normal" range. Roan et al. (1969) measured plasma and erythrocyte cholinesterase and serum levels of ethyl and methyl parathion. Serum levels of the parathion could not be correlated with cholinesterase levels. However, serum levels did correlate with the urine concentration of p-nitrophenol. Drevenkar et al. (1983) measured plasma and erythrocyte cholinesterase levels and urine concentrations of organophosphate and carbamate pesticides in formulating plant workers. No correlation could be made between urinary metabolites and cholinesterase activity. Bradway et al. (1977) examined cholinesterase, blood residues, and urinary metabolites in rats exposed to eight organophosphates under a controlled environment. No correlation was found between cholinesterase activity and blood residues or urine metabolite levels. The overall conclusion from these cited studies is that cholinesterase inhibition as an exposure indicator contains too many variables, known and unknown, to be of use (except in a very general sense).

Urinary metabolites of pesticides have been used for a variety of experimental goals. Swan (1969) measured paraquat in the urine of spraymen, Gallop and Glass (1979) and Wagner and Waring (1974) measured arsenic in timber applicator urine, Lieben et al. (1953) measured paranitrophenol in urine after parathion exposure as did Durham et al. (1972). Chlorobenzilate metabolite (presumably dichlorobenzilic acid) in citrus workers (Levy et al., 1982), phenoxy acid herbicide metabolites in farmers (Kolmodin-Hedman et al., 1983a) and organophosphate metabolites in the urine of the general public exposed to mosquito treatments (Kutz and Strassman, 1977) were detected. Davies et al. (1979) used urine metabolites of organophosphates and carbamates to confirm poisoning cases. These studies document exposure, but no estimation of exposure can be made from urinary metabolites alone. Other studies have used air sampling and hand monitoring, combined with urine levels (Cohen et al., 1979), and air plus cholinesterase plus urine sampling (Hayes et al., 1980).

The exposure pad method, combined with measurement of urinary metabolites, has been used to compare the effect of different application methods on worker exposure (Wojeck et al., 1983; Carman et al., 1982), formulating plant worker exposure (Comer et al., 1975) and homeowner exposure (Staiff et al., 1975).

Several researchers have used the exposure pad method, calculated a total estimated dermal dose, and attempted to correlate urine levels with this estimated dose (Wojeck et al., 1981, 1982, 1983; Franklin et al., 1981; Lavy et al., 1980, 1982). Lavy et al. (1980, 1982) failed to find any such correlation with 2,4-D and 2,4,5-T. Wojeck et al. (1983) found no paraquat in urine and consequently no relationship between dermal dose and urine level. However, the *group* daily mean concentration of urinary metabolites of ethion and the group *mean* total dermal exposure to ethion on that day correlated at the 97% confidence level (Wojeck et al., 1981). For arsenic, the cumulative total exposure

and daily urinary arsenic concentration correlated at the 99% confidence level (Wojeck et al., 1982). Franklin et al. (1981) found a correlation between 48 h excretion of azinphosmethyl metabolites and the amount of active ingredient sprayed. A significant correlation could not be made, however, between 48 h excretion and an exposure estimate. In the Franklin et al. (1981) experiment, a fluorescent tracer had been added to the spray mixture. Qualitatively, unpatched areas (face, hands, neck) also received significant exposure, perhaps leading to a weak correlation between the patch estimate and urinary metabolites. Winterlin et al. (1984) monitored the dermal exposure of applicators, mixer-loaders, and strawberry harvesters to captan using exposure pads. Although the applicator, mixer-loader group showed higher dermal exposure, no metabolite was detected in their urine while harvester urine had detectable levels.

The complexity of the urinary excretion kinetics of pesticides may render useless any search for a simple linear correlation between estimated dermal dose and urinary metabolites. Some experimenters have investigated this area. Drevenkar et al (1979) studied the excretion of phosalone metabolites in one volunteer. Excretion reached a maximum in 4-5 h, but was not complete in 24 h. Funckes et al. (1963) exposed the hand and forearm of human volunteers to 2% parathion dust. During the exposure, the volunteers breathed pure air and placed their forearm and hand into a plastic bag which contained the parathion. The exposure took place for 2 h at various temperatures. There was an increased excretion of paranitrophenol in urine with increasing exposure temperature. More importantly, paranitrophenol could still be detected in the urine 40 h later. In another human experiment, Kolmodin-Hedman et al. (1983b) applied methylchlorophenoxy acetic acid (MCPA) to the thigh. Plasma MCPA reached a maximum in 12 h and MCPA appeared in the urine for five days with a maximum at about 48 h. Given orally, urinary MCPA peaked in 1 h with about 40% of the dose excreted within 24 h. In a rat experiment, seven different organophosphates at two doses were fed to two rats per compound (Bradway et al, 1977). The rats were removed from exposure after the third day and blood and urine collected for the next ten days. The percent of total dose excreted in urine over ten days averaged (high and low doses): dimethoate, 12%; dichlovors, 10%; ronnel, 11%; dichlofenthion, 57%; carbophenothion, 66%; parathion, 40%; and leptophos, 50%. Very little of this excretion occurred beyond the third day after exposure. Parent compounds of ronnel, dichlofenthion, carbophenothion, and leptophos were found in fat on day 3 and day 8 after exposure. In another rat experiment, animals were given dermal and intramuscular doses of azinphosmethyl (Franklin et al., 1983). About 78% of the dermal dose had been excreted in urine in 24 h. Its rate of excretion reached maximum within 8-16 h, continued at about the same rate for another 16 h, and declined to a steady level 16 h thereafter. There was a linear relationship between dermal dose and urinary excretion. The intramuscular dose was excreted much more rapidly than the dermal dose. No apparent relationship existed between the intramuscular dose and urinary excretion.

Because these experiments illustrate the excretion differences between dermal, intramuscular, and oral dosing, the differences between compounds, and also raise questions about which urinary metabolite to monitor (Franklin et al., 1983), a very comprehensive experimental design would be necessary to correlate dermal exposure, absorption, and urinary metabolite levels. Statistical considerations centering around the large variation encountered among replicates probably make the economics of such an experiment in small animals, and certainly humans, prohibitive.

Several approaches to monitoring respiratory exposure are available. One common method was developed by Durham and Wolfe (1962) and employs a respirator with the collection pads protected by cones from direct spray. Another method uses the

personal air sampler with a pump carried by the worker and a collection device in the general breathing zone. In his review, Davis (1980) argued in several ways that the two methods suffer from the lack of efficacy data. That is, the trapping efficiency of a respirator or personal air sampler is seldom checked for the collection of both aerosols and vaporized materials. We agree with this assessment. Even when the collection efficacy is checked, the pesticide may have been applied in a solvent, and air subsequently drawn through the device. This is imprecise at best. Collection techniques which include both aerosols and vapor are more accurate and would better reflect actual field situations. The respirator with collection pads is the simpler method. It requires no adjustment for breathing rate, but does require a tightly fitting respirator.

Dermal Exposure Pads

Dermal exposure pads have been constructed of α-cellulose, cloth, polyurethane foam, and combinations of these materials. They are designed to collect spray materials and have been used for pesticides formulated as emulsifiable concentrates and wettable powders. These pads appear to work well. However, these collection devices are almost never assessed for pesticide loss. The question is, if the pad is left on the worker for 6 h, how much material evaporated or degraded in those 6 h? There would appear to be two ways to answer this question. Davis (1980) reviewed the practice of fortifying pads with the same pesticide-water mixture as in the field experiment. Alternatively, unfortified pads could be applied to the worker, with some left for 1 h and then removed, some left for 2 h and removed, and so forth. This latter test assumes that the exposure to the pads is equal for all exposure periods and ignores temperature effects. Fortified pads placed in an out-of-doors holding device appears to be the better approach. By removing and analyzing these pads at intervals, the approximate length of time a pad should be worn by a worker in the field can be determined. This is an important criterion toward "unquestionable" worker data, i.e., the ability to account for the behavior of the pesticide on the pad during the experiment.

Once the time of exposure and laboratory recovery studies are completed, storage stability should be determined. The simple expedient of storing one or two fortified pads with each worker's pad set will determine storage stability as extraction and analyses proceed. Resulting recoveries also serve as a check on the accuracy of laboratory extractions. The required number of these fortified pads depends on the size of the experiment. The criterion is to allow for enough measurements to statistically validate the quality of both storage and extraction. We use a minimum of three fortified pads per exposure day.

Placement of the pads on the body of the subject has many ramifications. If a total body exposure estimate is to be made, the calculation method should be considered. Davis (1980) and Popendorf and Leffingwell (1982) are good sources for these methods. Pads will be placed so as to optimize the total body estimate. Obviously, if the calculation requires a leg value, accuracy would dictate placing a pad on the leg. For areas where pads are inconveniently worn, such as the face, combinations of shoulder and upper body pad residues may be used as approximations. However, there is at least one published study in which face exposure was estimated (Franklin et al., 1981). Development of methods for measuring face exposure and for measuring exposure to other body areas where pads are not normally placed would be helpful to this research area.

The location of pads on the subjects is an important consideration. For those geographical areas where temperatures can be very warm during a spray season, data on where the greatest exposure occurs to the worker's body would be very helpful. These data would allow development of protective suits which do not attempt total coverage and might prove more comfortable. For in-

stance, the exposure of an applicator or mixer-loader on the backs of the arms and legs is not known. Whether the lower arms receive more exposure than the upper arms is seldom monitored. In many of our experiments, the lower arms received significantly more exposure than the upper arms, but the generality of this result is unconfirmed. If these data were available, comfortable protective suits utilizing relatively open mesh areas might be certifiably protective at this time. And, actual exposure estimates might, in fact, be reduced through their use. Certainly, taking these additional data adds extra work and expense to an exposure study, but the long-term benefits might be substantial.

Mixer-loader and Applicators vs. Harvesters

Applicators and mixer-loaders certainly receive different levels and types of exposure than do harvesters. The mixer-loaders are exposed to concentrate a well as drift; applicators are primarily exposed to drift and the tank mixed material. The reentering harvester is exposed to a presumably homogeneous application of pesticide on fruit, leaf, and soil surfaces. Both groups may also be exposed by working on or around contaminated machinery and in or around contaminated loading areas.

For harvesters, different sources of variation exist, but these may not be extreme. Theoretically, harvesters are exposed only to the residues remaining in the field, and most heavily when working in that field. The experiment appears simple. Pads are placed on the body of the harvester at various locations, the residues on leaves, fruit, and soil are measured, and the appropriate correlations are made.

For the experimenter, however, there are all sorts of possible constructions. Where should the pads be located? Should they be placed inside or outside the clothing? Will clothing chosen by the worker suffice or should standard clothing be issued? Was the field sprayed during 1 h, 1 day, or 3 days? If the spraying took longer than one day, where should the workers start working? Will they overlap sprayed sections as the work progresses? How many daily residue samples should be taken as a consequence? Should pads with a surgical gauze front be used or would polyurethane foam be satisfactory? How should these pads be assessed for residue loss? How long should the worker wear the pads? Is the pesticide converted in the field into a toxicologically important metabolite? Can it be extracted and analyzed? How should the urine be collected: 24-h urines or a timed grab sample? And finally, how many sampling periods (days) should the experiment entail in order to make the results statistically useful?

We offer these suggestions: for the initial experiment, the pads should be placed inside the clothing for lower and upper arm, chest, back, shoulders and shin exposure. For the upper body, the pads can be conveniently pinned inside an issued shirt. They can also be pinned inside the pants, but it should be noted whether the worker wears the same pants each day. For later experiments, a reduction in the number of pads may be possible. It is a mistake, however, to simply observe a harvest operation and decide *a priori* that only leg patches are necessary.

The time the pesticide application was made is important for several reasons. If the purpose of the experiment is to correlate field residues with worker exposure, then knowing the pesticide used and its application date can be crucial. An experiment of this type should begin at the legal reentry time and extend through at least two pesticide "half-lives." This insures the validity of the correlation of residues with exposure because a broad range of both has been utilized. This sampling time may last one week or longer. The area to be sprayed may be large. We have, for instance, used three spray machines simultaneously in order to assure a 1-day application. All harvesters are then exposed to the same daily residue over the sampling period.

When a "blind" harvester experiment is conducted and the application was made over a few days, the number of each type of

residue sample should be doubled and taken from where the harvesters are working that particular day. This will help with the overlap problem. Even if the experiment is only a 1- or 2-day experiment, reentry should commence as soon as possible after application. This assures some results at least, from an analytical standpoint, that may fit an existing model. If the workers reenter a field after ten days and the analytical chemist detects no residues because of low levels, little has been accomplished except the expense of time and money.

The most commonly used exposure pad for monitoring harvester exposures is faced with surgical gauze, backed with a-cellulose and glassine weighing paper. This pad has proven uncomfortable for the worker, difficult to attach, and takes time to prepare. We know of one instance where polyurethane foam pads were used (Brady, E., personal communication). They were convenient and may be efficient. However, there is no good method for assessing the residue collecting efficiency of these devices for a harvester exposure experiment. In spite of years of research in this area, the transfer process of field surface residues to the body of the harvester is not known with certainty. Probably foliar and field dust are primarily involved. How, then, is the efficiency of a collection device for a harvesting operation measured? The researcher is presently confined to the application of pesticide-laden dust or a pesticide solution to the exposure pad, followed by a disappearance study. Although the disappearance study may indicate a 50% loss from a pad in, say, 2 h, the pads may have to be worn longer. The reason is because exposure for a harvester is generally low and enough residue must be collected for analyses. We attach the pads just before workers enter the field in the morning and remove them 4-5 h later at the noon break. The amount detected on the pads can be corrected according to the disappearance experiment, but this correction is not entirely reliable since the pesticide may disappear at a different rate when attached to dust, as may have been the case in the field.

The presence of a toxic metabolite on foliage or in soil and the possible consequence to harvesters have been reviewed (Gunther et al., 1977; Nigg and Stamper, 1982). We mention this consideration because of its importance to harvesters and because the urine analyses may have to account for the excretion products of these metabolites. Urine collection from harvesters is not difficult. A timed grab sample from the start of work until the noon break has provided excellent correlations between residue levels on foliage and urinary metabolites in harvester (Nigg et al., 1984). We attribute this to the greater likelihood of homogeneous exposure to a harvester than to an applicator or mixer-loader.

Worker Methods and Work Rates

For the applicator, mixer-loader group the type of equipment used, the number of tanks applied per unit time, the concentration of the tank mix, and the loading method all affect the exposure process. This has been known for years and is described in many published reports (Davis, 1980; Nigg et al., 1984).

For harvesters, there are only a few field experiments described in the literature. The crop harvesting method has been studied and some reports exist which can be compared. What seems apparent from these reports is that the exposure process is similar for the harvesting of such tree fruits as citrus and apples. At least, the proportion of harvester exposure to pesticide on the leaf surface is the same. For other types of crops this proportion may be different.

Regardless of crop type, the work rate appears to be related to exposure. This means that the number of boxes picked, crates loaded, tassels removed, etc., is confounded with residue levels in affecting exposure. The individual worker's production delimits the contact with the plant, a subject which has been studied using movies and time analysis (Wicker and Guthrie, 1980), and estimated with surveys (Wicker et al., 1980). Therefore, work rate data should be gathered for each subject; it may explain variation in urinary or dermal exposure unaccounted for by field residues.

Extraction Methods—Rates of Disappearance

There has been some concern over the method of pesticide extraction, particularly for harvester exposure residues. For applicators and mixer-loaders, methods can be developed as needed with defined substrates. For the extraction of leaf, fruit, and soil surface residues, peculiar to harvester exposure studies, a standard methodology has been adopted by many researchers (Iwata et al., 1977; Spencer et al., 1977). Fruit and leaf surface residues are recovered with organic solvents from a mild soap solution in which they have been shaken. Soil surface residues are recovered by vacuuming surface soil through a 100-mesh screen. However, at least for foliar residues, some experimenters shake leaves in organic solvents (Ware et al., 1975, 1980). These organic solvent residue data may be higher and lead to slower calculated rates of disappearance, making it *appear* that the worker is exposed to higher residues of longer duration. Models of exposure based on the soap solution method have been and are being produced. A model developed for one chemical is then used for another. Solvent residue data for a chemical could be alternatively used in these models once the relationship between the organic solvent and soap solution methods is understood and quantified.

Harvester Exposure

Harvester exposure to pesticides has been the subject of several reviews (Davis, 1980; Gunther et al, 1977; Nigg and Stamper, 1982). Since pesticide may be transported to the harvester primarily on surface dust, the dermal exposure pads are faced with 16-ply surgical gauze. Respiratory exposure is usually not measured in harvester experiments.

Using the total body exposure estimation method, with dermal pads and handwashes, two models of tree harvester exposure as a function of leaf residue level have been produced (Popendorf and Leffingwell, 1982; Nigg et al., 1984). These are substantially the same model and agree with unpublished data from Washington apples (Davis, J., personal communication).

Applicator exposures may range from 69 mg/h (Wojeck et al., 1982) to 15,000 mg/h (Wojeck et al., 1981) while tree fruit harvester exposures range from 0.07 mg/h (Spear et al, 1977) to 2.35 mg/h (Nigg et al., 1984). While harvesters are exposed to less contaminating material *per se* than applicators and mixer-loaders, the quality of their exposure may be different. The applicator or mixer-loader is exposed to the parent compound only, whereas the harvester or any laborer reentering a treated area may be additionally exposed to a metabolite many times more toxic than the parent.

Is one situation more dangerous than the other? Acute poisoning cases for both situations are documented. We return to this point later in connection with protective strategies. It would appear that the *chronic* liability to an applicator/mixer-loader would be potentially greater because of the larger dose. Significant exposure to the small acreage farmer who participates in all farming operations is probably both chronic and acute.

Application Methods

Pesticide exposure rates measured during various application methods are presented in Table 1. Unfortunately, most of these studies employed different experimental designs. Either the dermal exposure pads were located differently or the estimated total body doses were made solely on the basis of body areas not covered by normal work clothing. In some cases (Wojeck et al., 1981, 1982, 1983) calculated doses were determined as if no clothing were worn at all. Nonetheless, a rough order-of-magnitude comparison is justified. It shows that the airblast method generally leads to more exposure, a point also made by Wolfe et al. (1972). Boom sprayer exposures are higher than for handsprayers, and handsprayers are more exposed than helicopter loaders.

Application method	Pesticide	Mean exposure level	Reference
Airblast	Carbaryl	59.1	Comer et al., 1975
Airblast	Ethion	1850	Wojeck et al., 1981
Airblast	Lead arsenate	95	Wojeck et al., 1982
Airblast	Various pesticides	200	Wolfe et al., 1972
Helicopter-Loader	2,4-D	.63	Lavy et al., 1982
Moderate Boom	Paraquat	168.6	Wojeck et al., 1983
High Boom	Paraquat	18.4	Wojeck et al., 1983
Low Boom	Paraquat	.40	Staiff et al., 1975
Low Boom (Shielded)	Paraquat	28.5	Wojeck et al., 1983
Low Boom	DNOSBP	131.1	Wolfe et al., 1961
Low Boom	Na-DNOC	39.6	Wolfe et al., 1961
Low Boom	Diallate	70	Dubelman et al., 1982
Handgun-Airboat	Diquat	1.82	Wojeck et al., 1983
Hand Sprayer	Paraquat	.29	Staiff et al., 1975
Handgun	Carbaryl	55	Leavitt et al., 1982

Body Areas

The studies in Table 1 generally agree on two counts. Hands account for 60-95% of the total estimated exposure for applicators and mixer/loaders, and in almost every case metabolites can be found in the urine.

Although a comparable quantity of data is not yet available for harvesters, gloves may be a useful protective device (Wicker et al., 1979). Hand exposure is higher than forearm exposure for strawberry harvesters (Zweig et al., 1983). However, in a study where pads were placed on various body areas of citrus harvesters, hands accounted for only about 10% of the total estimated exposure (Nigg et al., 1984).

Protective Strategies

The major requirement for protecting farm workers from pesticide exposure is reliable information. Many chemical companies market pesticides by touting the low toxicity of the pesticide formulation. The formulation may affect the dose, but not the intrinsic toxicity of the chemical. A good general rule is that the more acutely toxic the chemical, the more pesticide poisoning cases it will produce. The pesticide salespeople, however, may not even know the toxicity of the active ingredient. They are exposed to little, if any, of their product so that safety is an easy claim to make. In our experience, those salespeople who have been poisoned take a reticent approach. The poisoning history of the pesticide is of critical importance and, while chemical companies may have this information, they certainly do not advertise it. The argument that use levels also contribute to poisoning cases is logical, but this is a misleading and dangerous argument. Who can predict the actual use level of a chemical? Toxicity alone is the most important factor.

There are several basic precautionary measures suggested by the data in our cited references.

1. Regardless of the application method, the hands of applicators and mixer-loaders receive the highest level of exposure. Frequent washing of the hands with soap and water, and the washing of equipment prior to maintenance, appear to afford the best protection. Cloth gloves are

not recommended for this group because they rapidly become contaminated and can even exacerbate hand exposure. This is also true of rubber or other impermeable gloves which are re-used.

2. Clean clothing, including clean shoes and a wide-brimmed hat, provide substantial protection for the pesticide applicator and mixer-loader. In lieu of daily clothing changes, disposable protective suits are also very adequate.

3. At least 24 h should elapse before harvesters enter a pesticide treated area, and the area should be dry. The longer the time period before reentry, the safer rhe reentry will be, whether the field is wet or dry. An exception to this rule is a greenhouse, an exposure situation which needs study for all work tasks.

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