

ORIGINAL RESEARCH

Acephate exposure and decontamination on tobacco harvesters' hands

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Agricultural workers manually harvesting tobacco have the potential for high dermal exposure to pesticides, particularly on the hands. Often gloves are not worn as it hinders the harvesters' ability to harvest the tobacco leaves. To enable harvesters to remove pesticide residue on the hands and decrease absorbed doses, the EPA Worker Protection Standard requires growers to have hand-wash stations available in the field. The purpose of this study was to measure the concentration of acephate residue on the hands of tobacco harvesters, and the effectiveness of hand washing in reducing the acephate residue. Hand-wipes from the hands of 12 tobacco harvesters were collected at the end of the morning and at the end of the afternoon over 2 consecutive days. Each harvester had one hand-wipe prior to washing his hands, and the other hand-wipe after washing his hands with soap and water. In addition to the hand-wipe samples, leaf-wipe samples were collected from 15 tobacco plants to determine the amount of acephate residue on the plants. The average acephate level in leaf-wipe samples was 1.4 ng/cm². The geometric mean prewash and postwash acephate levels on the hands were 10.5 and 0.4 ng/cm², respectively. Both prewash (P -value = 0.0009) and postwash hand (P -value = 0.01) samples were positively correlated with leaf-wipe concentrations. Tobacco harvester position tended to influence hand exposure. Hand washing significantly reduced acephate levels on the hand, after adjusting for sampling period, hand sampled, job position, and leaf-wipe concentration (P -value \leq 0.0001) with levels reduced by 96%. A substantial amount of acephate was transferred to the hands, and while hand washing significantly reduced the amount of residue on the hands, not all residue was removed. *Journal of Exposure Analysis and Environmental Epidemiology* (2003) 13, 203–210. doi:10.1038/sj.jea.7500271

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Introduction

Dermal exposure to pesticides constitutes the major route of pesticide exposure for agricultural workers, with the hands often accounting for most of the dermal exposure (Popendorf et al., 1979; Zwiig et al., 1983; Winterlin et al., 1984). Agricultural harvesters who manually harvest crops are potentially at risk of high hand exposure to pesticides due to foliar contact. Traditional engineering controls are not feasible for reducing pesticide exposure among agricultural field workers and personal protective equipment (PPE), such as chemical-resistant gloves, are not often used due to environmental factors (hot weather), potential for entanglement in machinery, and loss of dexterity. One potential exposure mitigation measure is to provide hand-washing facilities for field workers.

In an effort to reduce exposure to pesticides via the hands, the US Environmental Protection Agency (EPA), in their Worker Protection Standard (WPS), requires that hand-washing facilities and supplies be provided for agricultural field workers within a quarter mile of their work location for 30 days after a pesticide application (EPA, 1992). However, very little data are available to indicate whether or not hand washing is effective in reducing exposure to pesticides. Campbell et al. (2000) investigated four solvents, including soap and water, for their ability to remove four pesticides from an *in vitro* porcine skin model. Soap and water removed between 49 and 56% of the pesticides 90 min after application. In a preliminary method evaluation study for the purpose of investigating the effectiveness of hand washing at reducing pesticide exposure among harvesters, Boeniger et al. (2000) found that hand washing reduced malathion hand residues by 59% when sampling the whole hand and by 34% when sampling only the forefinger and thumb. However, these results must be interpreted with caution as the sample size was small and the primary purpose of this study was to evaluate wipe sampling methodology.

Studies have been conducted investigating the effectiveness of hand washing as a sample method. Brouwer et al. (2000)

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conducted a literature review of hand-sampling methods and found that hand-wash sample efficiency for various pesticides, at various loadings, and using various solvents, ranged from 23 to 96%. In this review, three studies are cited where soap and tap-water washing was investigated for its efficiency at removing mancozeb, methiocarb, methomyl, propoxur, and vinclozolin. The sampling efficiency ranged from 46 to 96%. Fenske and Lu (1994) and Fenske et al. (1998) investigated the effectiveness of hand washing with isopropanol or ethanol and found that wash sample efficiency ranged from 21 to 43% for chlorpyrifos and 68 to 91% for captan. However, these studies were investigating hand washing as a sample method, the procedures of which differ substantially from washing hands with soap and water to clean them.

In an effort to determine the extent to which hand washing with soap and water removes pesticide residues from the hands of field workers, agricultural field workers who manually harvest tobacco were sampled for acephate exposure on their hands. The purpose of the study was two-fold: (1) to determine the extent of acephate residue on the hands of harvesters, and (2) to determine the amount of acephate that was removed from the hands after washing with soap and water. The objective of the study was to ascertain whether or not hand washing with soap and water in the field is an effective means of removing pesticide residue on the hands.

Methods

Sample Collection

Two crews of six tobacco harvesters each were enrolled in the study. The harvesters were Hispanic males harvesting the bottom three or four leaves of flue-cured tobacco in fields near Kinston, North Carolina on July 16 and 17, 2001. Five fields were harvested, and each field was sprayed with Acephate 75 SP (EPA Reg. # 51036-236, 75% acephate) between 6 and 11 days prior to harvesting at an application rate of 1.12 kg

product (0.84 kg active ingredient) per hectare (Table 1). Each crew used a tobacco-harvesting machine, which moved slowly down the tobacco rows, with four harvesters seated near the ground collecting leaves and placing them onto conveyor belts, and two workers on a platform above them taking the leaves from the conveyor belts and placing them in a bin at the rear of the machine (Figure 1).

Hand-wipe samples were obtained from 12 workers at four sampling times (day 1 morning, day 1 afternoon, day 2 morning, and day 2 afternoon). Each sample was collected after approximately 4 h of field work. Two hand-wipe samples (one left-hand and one right-hand sample) were obtained from each worker at each of the sampling times. For samples collected in the morning on day 1, workers were randomized to have either (i) both hands sampled prewash, or (ii) both hands sampled postwash. This method was initially chosen to account for potential handedness in tobacco harvesting and to increase the concentration of acephate residue on the samples, thereby reducing the potential number of samples with non-detectable concentrations. However, after observing the harvesters, it became apparent that right and left hands contacted the tobacco leaves equivalently. The workers' hands were so heavily covered with plant residue and soil, the investigators believed few wipe samples from only one hand would be below the limit of that detection (LOD). Therefore, for all the other samples, the sampling method was changed to account for inter-worker variability by randomizing the workers to have either (i) their right hand sampled prewash and then their left hand sampled postwash, or (ii) their left hand sampled prewash and then their right hand sampled postwash. The workers were instructed to wash their hands as they normally would.

The hand-wiping method described in Geno et al. (1996) was used to sample for pesticide residue. The method involves wiping one entire hand with a 10 cm × 10 cm Sof-Wick[®] dressing sponge (Johnson & Johnson, Arlington, TX, USA) moistened with 10 ml of 100% isopropanol, and then wiping each finger of the same hand with a second

Table 1. Summary statistics for measured leaf-wipe acephate levels by field.

Field	Days since field sprayed	<i>n</i>	Time harvested	Crew	AM (ng/cm ²)	SD (ng/cm ²)	Range (ng/cm ²)	Tukey-Kramer grouping ^a
1	7	6	All day 1 Aft day 1	1 2	1.3	0.4	0.7–1.7	A
2	8	3	All day 2	1	0.9	0.4	0.4–1.3	A
3	8	3	Morn day 2	2	1.0	0.4	0.6–1.4	A
4	11	3	Aft day 2	2	2.7	1.0	2.0–3.8	B
5	6	0	Morn day 1	2	NA	NA	NA	
Overall		15	—		1.4	0.8	0.4–3.8	

AM = arithmetic mean, SD = standard deviation, NA = not available.

^aMeans with the same letter are not significantly different at *P*-value < 0.05.



Figure 1. Tobacco-harvesting machine.

dressing sponge. Investigators wiped the hand by first putting on a clean pair of nitrile gloves. The whole hand was thoroughly wiped with the first moistened sponge. The sponge was unfolded and folded back on itself to present a clean surface and the hand was wiped further. This was repeated on the fingers with the second sponge. Both sponges were placed in the same sample jar for analysis. A clean pair of nitrile gloves was worn for each sample collected.

In addition to the hand-wipe samples, tobacco leaf-wipe samples were also taken from four of the five fields harvested. Owing to a busy schedule on the first morning of the study, the field staff was unable to collect leaf samples from one field. Three tobacco plants from three of the fields harvested were selected for wipe sampling. Six plants were sampled from one large field where both crews were working. A total of 15 plants were sampled. A 200 cm² area on the top of selected tobacco leaves was wiped. Two leaves per plant, a bottom leaf and an upper leaf, were wiped and combined into one sample. To wipe the leaf, a 10 cm × 20 cm plastic template was placed on top of the leaf surface and held fast using four small clamps. A 10 cm × 10 cm Sof-Wick[®] dressing sponge, moistened with 10 ml of 100% isopropanol, was folded in half and wiped over the length of the template three times. The sponge was then folded back onto itself, so that a 10 cm wide clean surface was presented, and a second wipe, perpendicular to the first, was taken over the width of the template three times. The sponge was again folded so that a 10 cm wide clean surface was available and a third wipe, adjacent to the second and perpendicular to the first, was performed three times. A clean pair of nitrile gloves was worn for each sample collected.

Sample Extraction and Analysis

Each sample, consisting of two gauze dressing sponges (wipes), was placed in a 22 ml accelerated solvent extractor

(ASE) cell. The sample was fortified with 100 ng of the surrogate recovery standard diethyl acetoamidomalonate (DEAA; 10 μl of a 10 ng/μl solution), which is structurally similar to acephate with respect to functional groups; any void space in the cell was filled with muffled industrial quartz (Accusand). The wipes were extracted on the ASE (Dionex Inc.) at 2000 psi and 100°C using 1:1 hexane:acetone through two extraction cycles. The 25 ml extract was diluted to 40 ml and 10% was removed for archival purposes. The remaining extract was transferred to a TurboVap tube (Zymark Inc.) with rinses, and concentrated to approximately 1 ml (water bath at 50°C, nitrogen flow at 5–10 psi). The solvent was exchanged into hexane in a two-step process for complete removal of acetone and isopropanol prior to the clean-up step. The hexane extract was applied to a silica solid-phase extraction (SPE) cartridge (J.T. Baker, 1000 mg) that had been conditioned with 20% acetone in ethyl acetate and hexane. The cartridge was eluted in sequence with hexane (discarded), 15% diethyl ether in hexane (discarded), and 20% acetone in ethyl acetate (collected for analysis). The eluent was concentrated to approximately 1 ml in a TurboVap, spiked with 100 ng of the internal standard fluorine-d₁₀ (10 μl of a 10 ng/μl solution). Every sample extraction batch consisted of nine field samples, one field matrix blank, one laboratory matrix blank, and one laboratory matrix spike; the fortified matrix samples received a spike of either 100, 500, or 1000 ng of acephate. Two extraction sets, which consisted of 18 field samples and six QC samples, were analyzed as a single GC/MS analysis set together with seven calibration curve solutions, spanning acephate concentrations of 50–1000 ng/ml. Standards were interspersed among samples in the GC/MS run order.

Samples and standards were analyzed using an HP 6890 GC/MS in the multiple ion detection (MID) mode. The GC column was a 30 m Rtx-35ms (0.25 μm film thickness,

0.25 mm diameter; Restek). The GC injector was 220°C; the column was initially held at 80°C for 2 min, and then programmed at 15°C/min to 160°C, after which it was programmed at 5°C/min to 280°C, for a total run time of about 31 min. The injection liner was replaced after each analysis set. The approximate retention times for DEAA, acephate, and fluorine-d₁₀ were 11.0, 11.1, and 12.4 min, respectively. The monitored ions were: *m/z* 136, 142, 168, 183 for acephate (*m/z* 142 as the quantification ion); *m/z* 102, 144, 172 for DEAA (*m/z* 102 as the quantification ion); 174, 176 for fluorine-d₁₀ (*m/z* 176 as the quantification ion). Identification was based on these ions present at the correct retention time (± 0.03 min) and in the correct ratio.

The internal standard method of quantification was used with a linear calibration curve generated using a least-squares analysis of the calibration data. In extracts where the acephate concentration exceeded the calibration range, the sample was diluted, respiked with internal standard, and reanalyzed. The quantity of acephate was corrected by the archival amount and the recovery of the surrogate recovery compound (DEAA) in that sample.

Tests were conducted to assess the precision and accuracy of the method. To do so, moistened wipes were wiped across a 10 cm \times 15 cm section of pig skin (obtained from the local rendering plant) that had been inoculated with 1 g of soil and 0.5 ml of plant juices; the desired amounts of acephate and DEAA were then added. Recoveries for acephate were: 129 \pm 28% for 80 ng fortification ($n = 7$); 116 \pm 7% for 8 μ g fortification ($n = 4$); 92 \pm 13% for 800 μ g fortification ($n = 4$). Recoveries for DEAA were: 120 \pm 32% for 100 ng coapplied with 80 ng acephate ($n = 7$); 97 \pm 7% for 100 ng coapplied with 8 μ g of acephate; 102 \pm 15% for 100 ng coapplied with 800 μ g of acephate. Storage stability tests for 8 μ g of acephate on similarly prepared wipe samples held at -20°C showed about a 20% loss over a 28-day hold time: 92 \pm 4% day 0 ($n = 3$); 83 \pm 3% day 7 ($n = 3$); 74 \pm 24% day 28 ($n = 3$). The laboratory-fortified matrix QC samples that were analyzed with field samples had the following recoveries: 74 \pm 32% for 100 ng acephate ($n = 4$), 84 \pm 9% for 500 ng acephate ($n = 3$), and 78 \pm 19% for 1000 ng acephate ($n = 3$). Acephate was not detected in any field ($n = 11$) or laboratory ($n = 12$) blank sample. The limit of quantification (LOQ) was 50 ng/sample and the LOD was approximately 30 ng/sample.

Data Analysis

For hand-wipe samples, values of acephate (ng/sample) below the LOD were estimated by dividing the LOD by 2 since the per cent of undetectable samples was relatively low and the distribution of measured acephate levels was highly skewed with a geometric standard deviation greater than 3.0 (Hornung and Reed, 1990). Acephate levels (both measured and corrected) were converted from ng/sample to ng/cm² using a surface area of 420 cm²/hand (EPA, 1997) for hand-wipe samples and 400 cm² for leaf-wipe samples. The

corrected acephate hand-wipe levels were highly skewed to the right. A log (base 10) transformation was applied to the corrected acephate hand-wipe levels prior to statistical modeling. All the data presented here are derived from the corrected values.

Analyses were done using SAS version 8.2 (SAS Institute Inc., 1999). Descriptive statistics for leaf-wipe acephate levels were computed by field. When comparing mean leaf-wipe acephate levels for the fields, *P*-values were adjusted using the Tukey–Kramer adjustment for multiple comparisons of unbalanced data. Descriptive statistics for pre- and postwash hand-wipe acephate levels were computed by sample time and by sample field.

Since each worker had eight hand-wipe measurements taken over a 2-day period, the MIXED procedure in SAS was used to model hand-wipe acephate levels treating worker as a random effect. Sample day (day 1, day 2), sample time (morning/afternoon), and an interaction between day and time were included in the models as fixed effects to adjust for any time-of-sampling effect on hand-wipe levels. Sample hand (left/right) was included in the models as a fixed effect to test for differences in levels between the hands. Harvester position (top/bottom) on the tobacco-harvesting machine was included in the models to test for differences in hand-wipe levels between the two harvester positions. Initial models considered pre- and postwash hand-wipe samples separately, then all samples were combined, and sample order (prewash/postwash) was included as a fixed effect to test for the effect of hand washing on hand-wipe acephate levels. A term representing the field-specific leaf-wipe mean was included in the models as a continuous covariate to adjust the hand-wipe levels for leaf-wipe levels. However, since leaf-wipe samples were not available for all fields, hand-wipe results are presented both unadjusted and adjusted for leaf-wipe mean. A linear trend test was used to test for trend in the hand-wipe acephate levels over time. Both compound symmetric and first-order autoregressive covariance structures were tested. Akaike's information criteria (AIC) are used to compare the model fit. Results are presented as adjusted geometric means by taking the antilog of the adjusted means of the log-transformed values. All significance testing was done at the 0.05 level.

Results

In all, 15 leaf-wipe samples were obtained from four of the five fields harvested. Acephate in all 15 leaf-wipe samples was above the LOD. The acephate residues on the leaves of tobacco plants were fairly similar in three of the fields. However, field 4 had residue levels two to three times that of the other fields ($P < 0.001$). Overall, the mean acephate level for leaf-wipe samples is 1.4 ng/cm², with a range from 0.4 to

3.8 ng/cm² (Table 1). Field-specific mean levels of acephate from leaf-wipe samples ranged from 0.9 to 2.7 ng/cm².

In total, 96 hand-wipe samples were collected, of which three prewash and eight postwash samples (11.5%) had acephate levels below the LOD of 30 ng/sample. Summary statistics for pre- and postwash hand-wipe acephate levels are presented in Table 2 by sample day and sample time and overall. The geometric mean (GM) acephate level for all

Table 2. Summary statistics for measured pre- and postwash hand-wipe acephate levels by sampling period.

Day	Time	Sample order	n	GM (ng/cm ²)	GSD	Range (ng/cm ²)
1	Morning ^a	Prewash	12	9.1	5.6	0.07–46.5
		Postwash	12	0.1	2.3	0.06–1
1	Afternoon ^b	Prewash	12	4.8	4.4	0.56–103
		Postwash	12	0.3	3.6	0.04–1.2
2	Morning ^b	Prewash	12	10	5.2	0.36–44.9
		Postwash	12	0.4	2.3	0.07–1
2	Afternoon ^b	Prewash	12	27.7	3.6	1.5–257
		Postwash	12	1.4	2.4	0.2–3.7
Overall		Prewash	48	10.5	5.1	0.07–257
		Postwash	48	0.4	3.7	0.04–3.7

GM = geometric mean, GSD = geometric standard deviation.

^aWorkers were randomized to have both hands sampled prewash or both hands sampled postwash.

^bWorkers were randomized to have either (i) their right hand sampled prewash and then their left hand sampled postwash, or (ii) their left hand sampled prewash then their right hand sampled postwash.

Table 4. Adjusted geometric mean acephate levels (ng/cm²) obtained from the mixed-effects models for hand-wipe samples both unadjusted and adjusted for field leaf-wipe mean.

Effect	Level	Model not adjusting for leaf wipe ^a			Model adjusting for leaf wipe ^b		
		Prewash	Postwash	P-value (pre versus post)	Prewash	Postwash	P-value (pre versus post)
Hand	Right	5.8	0.39	0.0001	5.0	0.46	0.0001
	Left	10.9	0.32	0.0001	12.6	0.34	0.0001
	P-value (right versus left)	0.16	0.45		0.0024	0.20	
Job	Top of harvester	4.6	0.28	0.0001	4.6	0.31	0.0001
	Bottom of harvester	13.5	0.44	0.0001	13.6	0.50	0.0001
	P-value (top versus bottom)	0.067	0.33		0.037	0.27	
Sample time	Day 1 morning	5.6	0.12	0.0001	6.1	0.21	0.0001
	Day 1 afternoon	3.8	0.23	0.0001	3.9	0.24	0.0001
	Day 2 morning	8.8	0.41	0.0001	12.6	0.51	0.0001
	Day 2 afternoon	20.8	1.29	0.0001	13.1	0.97	0.0001
	P-value (linear trend)	0.0075	<0.0001		0.037	<0.0001	

^aThe model uses n=96 hand-wipe samples from 12 workers.

^bThe model uses n=84 hand-wipe samples from 12 workers. In all, 12 hand-wipe samples obtained in the morning on day 1 are excluded since the corresponding leaf-wipe data are not available for these samples.

Table 3. Summary statistics for measured prewash and postwash hand-wipe acephate levels by field

Field	Sample order	n	GM (ng/cm ²)	GSD	Range (ng/cm ²)
1	Prewash	18	6.6	4.0	0.6–103
	Postwash	18	0.2	3.2	0.04–1.2
2	Prewash	12	12.6	4.2	0.5–64.7
	Postwash	12	0.7	2.8	0.07–2.4
3	Prewash	6	8.1	5.3	0.4–36.6
	Postwash	6	0.4	1.6	0.2–0.68
4	Prewash	6	59.0	2.3	32.1–257
	Postwash	6	2.3	1.3	1.7–3.7
5	Prewash	6	6.5	10.3	0.07–46.5
	Postwash	6	0.1	1.7	0.06–0.2

GM = geometric mean, GSD = geometric standard deviation.

prewash hand samples is 10.5 ng/cm², with a range from 0.07 to 257 ng/cm². The GM acephate level for all postwash hand samples is 0.4 ng/cm², with a range from 0.04 to 3.7 ng/cm². Overall, hand washing reduced the GM acephate level by 96%. Summary statistics for pre- and postwash hand-wipe acephate levels are presented in Table 3 by field. Both pre- and postwash hand-wipe acephate levels from field 4 were considerably higher than levels from the other fields.

Results of statistical modeling of the hand-wipe acephate levels are presented in Table 4. Two models are presented. The first model considers the effects of hand sampled (right/left), job position (top/bottom), sample day (day 1/day 2),

sample time (morning/afternoon), and wash status (prewash/postwash) on hand-wipe acephate levels. The second model further adjusts hand-wipe levels for field-specific leaf-wipe levels, but utilizes fewer samples due to missing leaf-wipe levels from one field. Both models incorporate the compound symmetric covariance structure, which provided a better fit than a first-order autoregressive covariance structure (not shown). Since results are consistent between the two models, the second model is presented here. Hand washing significantly reduced acephate levels on the hand (P -value ≤ 0.0001). Prewash acephate levels were higher on the left hand than the right hand (adjusted GM 12.6 versus 5.0 ng/cm², P -value = 0.0024). Postwash acephate levels were similar on the left and right hands. Prewash acephate levels were higher for subjects working on the bottom of the tobacco harvester, collecting leaves from the plants, compared to subjects working on top of the tobacco harvester, moving leaves from the conveyor belt to the bins (adjusted GM 13.6 versus 4.6 ng/cm², P -value = 0.037). Postwash acephate levels were similar between the job groups. Prewash acephate levels increased on day 2 (test for linear trend P -value = 0.037) and postwash acephate levels increased over the sampling periods (test for linear trend P -value ≤ 0.0001). In addition, hand-wipe acephate levels were positively related to leaf-wipe levels for both prewash (P -value = 0.0009) and postwash (P -value = 0.015) samples.

Discussion

A substantial amount of acephate is transferred to the hands when harvesting tobacco sprayed with acephate. Owing to repeated contact with numerous tobacco leaves, acephate was concentrated on the hands of the tobacco harvesters. Clearly, washing hands had a large and significant effect on the amount of acephate residues on the hands. Washing the hands with soap and water reduced the residues by 96% on an average. Despite some criticisms of the WPS (EPA, 1992) requirement for providing hand-washing facilities as being difficult to implement, it is evident that these facilities can substantially reduce residues on the hands.

However, the data presented here only deal with acephate, a highly water-soluble organophosphate compound, and washing hands with soap and water. Caution should be exercised when interpreting these data with other pesticides and other hand-washing methods. Other studies have found that washing removed anywhere from 23 to 96% of pesticides, depending on the pesticide, the solvent used for cleansing, the time since exposure, and the amount of pesticide originally on the skin (Pelletier et al., 1990; Boeniger et al., 2000; Brouwer et al., 2000; Campbell et al., 2000).

Washing with soap and water removed 59% of malathion residues from the hands of strawberry harvesters (Boeniger

et al., 2000). Campbell et al. (2000) investigated the removal of four pesticides with varying water solubilities (glyphosate, alachlor, methyl parathion, and trifluralin) from *in vitro* porcine skin with four solvents. The solvents used were 10% soap and water, 1-propanol, polyethylene glycol, and D-Tam. The removal of the pesticides was fairly similar for all solvents, with 1-propanol removing more pesticides than the other solvents with the exception of glyphosate, where soap and water removed the most. The amount of pesticide removed from the skin was affected by the solubility of the pesticide and the amount of pesticide on the skin. Pelletier et al. (1990) were able to remove 45–61% of 2,4-D from the backs of rats with soap and water 7 h after dosing. Additionally, they investigated other cleansing agents (water only, isopropanol, acetone, and Rad-Con, a foaming hand cleaner) and found that all were similar, removing approximately 60% of 2,4-D 7 h postapplication. Fenske and Lu (1994) found that the removal efficiency of chlorpyrifos with a standard hand-wash sample method using a 10% isopropanol/distilled water solution was generally lower with decreased pesticide loading.

The time interval between the last exposure and decontamination would also seem to be a factor in removing pesticides from the skin. Delaying cleansing to 23 h postapplication of 2,4-D generally reduced the percentage of 2,4-D removed from rat skin by approximately 20% over washing at 7 h postapplication (Pelletier et al., 1990). When rhesus monkeys were washed with various solvents, including soap and water, between 70 and 100% of Aroclor 1242 PCB was removed immediately following a 15 min skin application interval. The amount removed declined steadily with time, to where only 25–45% was being removed at 24 h postapplication (Wester et al., 1990). In an investigation of a hand-sampling method, where a hand is placed in a bag containing solvent and shaken, Fenske and Lu (1994) found that the removal efficiency of chlorpyrifos decreased from 43% immediately after exposure to 23% 1 h postexposure when a 10% isopropanol/distilled water solution was used as the solvent. However, time since exposure did not have an effect when ethanol was used as the solvent. In a similar investigation with captan, Fenske et al. (1998) saw the removal efficiency decrease from 78% immediately after exposure to 68% 1 h postexposure.

The fact that the tobacco harvesters washed their hands shortly after they finished harvesting, coupled with the high water solubility of acephate, might account for the high amount of acephate removed. A delay in washing would result in more acephate being absorbed into or bound to the skin, resulting in less acephate being removed by hand washing and more of it becoming bioavailable or potentially bioavailable.

Despite removing the majority of acephate, not all residue was removed with hand washing. We see a significant increase in postwash hand residues over the four sampling periods

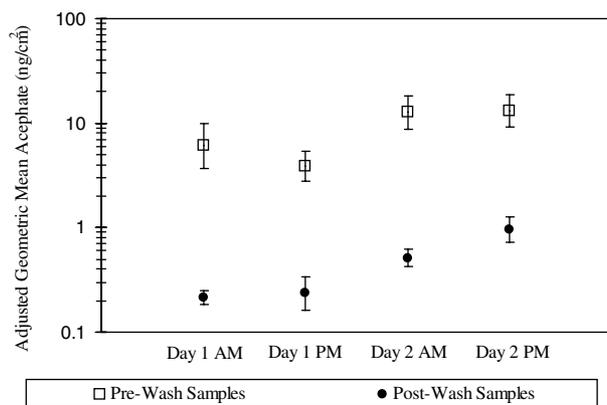


Figure 2. Adjusted geometric mean (± 1 standard error) pre- and postwash hand-wipe acephate levels *versus* sample time. Geometric means are adjusted for hand, job position, and leaf-wipe mean.

(Figure 2, test for linear trend P -value ≤ 0.0001). One possible explanation is that the workers became more lax in washing their hands as they became more comfortable with the study. However, the percentage decrease in residue on the hands after hand washing over the four sample periods remained consistent (99, 95, 96, and 95%), suggesting that this is not the case. More likely explanations include incomplete removal of acephate and/or higher leaf residues. However, even after adjusting for tobacco leaf residue, which was positively correlated with hand residues, the linear trend in postwash hand residues remained statistically significant. Caution should be exercised when interpreting this trend as only a small number of leaf-wipe samples were collected (three per field for three fields, six per field for one field) and therefore may not accurately reflect the average leaf residue for the entire field. Further, this study was not designed to investigate the effect of time on hand exposure. Samples were only collected over a 2-day period and this trend may not hold over a longer period of time.

Harvesters' exposures varied depending on the job task they performed. Harvesters at the bottom of the harvesting machine collecting the tobacco leaves tended to have greater hand exposure. They were in greater contact with the tobacco leaves, and contacted tobacco leaves more frequently than the harvesters at the top of the machine. Although not investigated in this study, the bottom workers would likely have substantial whole body exposure as they were completely covered by tobacco leaves when harvesting.

The removal efficiency of the hand- and leaf-wipe method employed in this study was not determined. This is a limitation to this study. The exposure values could be underestimated due to incomplete removal and hand-washing effectiveness results could be affected if the wipe method removal efficiency is different for different acephate loadings. Geno et al. (1996) reported good removal efficiency for chlorpyrifos (104%) and pyrethrin (92%) using this wipe

method on hands. Fenske et al. (1999) reported that hand wiping underestimated hand exposure for apple thinners exposed to azinphos-methyl. Brouwer et al. (2000) conducted a literature review on hand-wipe removal efficiencies and reported a range of 36–104%. They recommend that removal efficiency studies be done prior to conducting studies for risk assessment purposes using hand-wipe methods.

Conclusion

Substantial amounts of acephate residue are being transferred to the hands from tobacco leaves during harvesting. Hand washing with soap and water removes a significant amount of acephate residue from the hands, however, not all acephate is removed by washing. Acephate removal efficiency for the wipe method was not determined and is a limitation to this study.

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