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Effect of Laundering Procedures and Functional Finishes on Removal of Insecticides Selected from Three Chemical Classes

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ABSTRACT: Eleven pesticides from three chemical classes were chosen for comparison of residues after laundering. Pesticide was introduced to the fabric surface of one of three fabrics—unfinished (UN), renewable consumer applied fluorocarbon finished (RF), and commercially applied fluorocarbon finished (CM) fabric. The fabrics were laundered using one of three laundry treatments—a heavy-duty liquid detergent (HDL) alone, an HDL with a prewash spray, and an HDL with an agriculturally marketed pretreatment.

Gas chromatographic analysis showed that the fluorocarbon-finished fabrics absorbed only 10% of the pesticide absorbed by the UN fabrics. Residues after laundering were significantly different both among and within classes. Although both fluorocarbon finishes reduced absorption of pesticide, they did not facilitate removal of the contaminant through laundering. Laundry additives significantly aided residue reduction.

KEY WORDS: pesticide, pesticide residue, functional finish, soil-repellent finish, durable-press finish, surfactants, protective clothing, laundering

A major concern of agriculturalists today is contamination of clothing during mixing and application of pesticides. Pesticide contaminants can be difficult to remove from clothing. General recommendations have been made for the “best” methods of removal of pesticides from clothing in laundry [1-4].

The greatest imminent health risk from pesticides comes through primary

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exposure. Making persons exposed to pesticides more aware of dangers, of how to avoid contamination, and of how to deal with contaminated clothing may reduce the potential for adverse effects.

The effectiveness of laundering in removing pesticide is important in making contaminated clothing safe to wear. After the clothing has been laundered it is generally considered by most applicators to be clean; however, when the wearer is not aware of residues remaining in the clothing, contaminated garments provide a medium for exposing the skin to the pesticide [5,6], making dermal absorption possible [7,8].

A majority of studies that evaluated laundering variables included only one or two pesticides [9-16]. Based on these one or two-chemical studies, recommendations to maximize removal are being made for pesticides across the board [1-3]. In one of the few studies involving several chemicals, Lillie et al [17] found that differences in removal tend to occur among insecticides and that the best laundry procedures may not be best for all pesticides.

Highly concentrated active ingredient (AI) in the undiluted formulated material may be impossible to remove entirely from contaminated clothing. Easley et al [6] found that in fabrics contaminated with 54% AI emulsifiable concentrate methyl parathion (MeP), only 66.68% of the material was removed after ten machine washings.

Hot water [60°C (140°F)] contributed to increased removal of fonofos and alachlor on heavy fabric substrates [15]. Easley et al found decreased residues with elevated temperatures [49°C (120°F) and 60°C (140°F)] when working with 2,4-dichlorophenoxyacetic acid and amine (2,4-D) [12] and methyl parathion (MeP) [11]. Finley et al [18] also recommended hot water [60°C (140°F)] based on studies of MeP, toxaphene, and dichlorodiphenyltrichloroethane (DDT). Easter [13] found Guthion and captan removal to increase with temperature; however, Lillie et al [19] found removal of chlordane to be inversely related to water temperature.

Few attempts have been made in a single laboratory to compare pesticide residues after laundering within the same chemical class and between classes. In the work with diazinon, malathion, bromacil, propoxur, and chlordane, differences were found, but the solutions for each pesticide were at different concentrations of active ingredient, and an insufficient number of pesticides were tested to observe the effect of pesticide class as a causal factor in completeness of removal [17].

Livingston [20] also examined diazinon, chlordane, and carbaryl insecticides and the herbicide prometon for removal tendencies from all-cotton and all-polyester coveralls. In these studies of different concentrations of active ingredients, carbaryl and prometon were completely removed; diazinon and chlordane were more persistent. Chlordane was the most difficult to remove of the chemicals tested, with approximately 90% removal after a single laundering. Finley et al [18] have shown that pesticide soil removal is more difficult for fabrics contaminated with different pesticides and washed in the

same wash load. The Livingston study [20] was done with all the contaminated fabrics laundered together.

The pesticide class was theorized to have a significant influence on removal in a laundry study involving fonofos and alachlor [15]. Easter [13] found differences in removal between captan and Guthion. Captan residue was more difficult to remove from denim, while Guthion was more difficult to remove from Gore-Tex.

Pesticide removal by laundering has been paralleled to soil removal. Specific formulations are more responsive to procedures directed toward those selected soil types. Treatments for oily soils have been suggested to be more efficient in the removal of specific formulations [11,13].

Use of fabrics with a water-repellent finish may provide protection from chemicals [21]. In studies by Gold et al [22] and Leavitt et al [23], it was observed that the skin was exposed to 5 to 6% of the carbaryl coming in contact with conventional clothing worn by workers. A fluorocarbon finish was found to make a significant difference in the permeability of clothing to pesticides [24]. Kavar et al [7] found that penetration by dust was reduced by 60% after the addition of a fluorocarbon finish on the fabric. Neither of these studies addressed issues related to laundering.

The primary objective of these laundry studies has been to determine the most effective laundry practices. If these procedures are to be generalized to be used with more pesticides than those directly under study, bases for such generalizations must be established. The first phase of this two-phase study examined the similarities and differences in pesticide removal both between and within insecticide classes. The second phase evaluated the effectiveness of fluorocarbon finishes in providing protection after repeated launderings. This was an interdisciplinary study involving the departments of Textiles, Clothing and Design, Environmental Programs, and Agronomy at the University of Nebraska.

Procedures

Fabrics

Fabrics for the study were obtained from the Southern Regional Research Center (SRRC) of the U.S. Department of Agriculture (USDA). The fibers were blended, the yarns spun, and the fabrics woven by the Fabric Engineering and Development Research Group in the Cotton Textile Processing Laboratory of the SRRC under the direction of George Drake. All were 122.5-g/m², 50% cotton/50% polyester fabrics; the thread counts were 28 threads per centimetre in the warp and 32 threads per centimetre in the filling. The unfinished fabric (UN) had been boiled off and bleached during wet finishing.

One portion of the UN fabric was sprayed with a renewable consumer-applied fluorocarbon finish (RF) to achieve a dry weight gain of 0.55 to 0.80%.

The third fabric was finished with a commercially applied soil-repellent fluorocarbon finish (CM) designed to repel moisture. The commercial fluorocarbon formulation (Quarapel) was composed of Zepel D fluoropolymer (7.0%), Norane F fluorochemical extender (10.0%), Nykon NRW3 wetting agent (0.4%), and water (82.6%). It was pad applied at a net pickup of approximately 70%.

Fabric stripping was eliminated to allow evaluation of functional finishes. The outer 10% of the fabric in the warp direction was discarded [ASTM Test for Breaking Load and Elongation of Textile Fabrics (D 1682-64 [1975])]. Eight-centimetre square specimens were cut from each of the three fabrics. The specimens were conditioned [at $65 \pm 2\%$ relative humidity and $21 \pm 1^\circ\text{C}$ ($70^\circ \pm 2^\circ\text{F}$)] [ASTM Practice for Conditioning Textiles for Testing (D 1776-79)] prior to contamination.

Insecticides

Insecticides are divided into chemical classes according to their components. The three classes of insecticides included in this study were organophosphates, carbamates, and organochlorines. These three classes are the most widely used and present the greatest hazard in terms of human toxicity [25]. Because of their wide use, emulsifiable concentrate pesticide formulations were used in this study, except for carbofuran, which was available only as a flowable formulation.

A 1.0% field strength solution was prepared according to label directions, for each of the following insecticides: *organophosphates*—chlorpyrifos, diazinon, dichlorvos (DDVP), dimethoate, malathion, and methyl parathion; *carbamates*—carbofuran and propoxur; *organochlorines*—aldrin, chlordane, and lindane.

Specimen Contamination—A hand-held micropipette with microprocessor was used to apply a 0.2-mL aliquot of pesticide solution to each specimen. The entire aliquot was absorbed by the unfinished fabric; however, both fluorocarbon finishes made the specimen hydrophobic. After 10 s the specimen was held in a vertical position and the unabsorbed solution was allowed to roll off the fabric surface and into a waste receptacle. Prior to analysis, all the specimens were allowed to air dry (18° to 22°C , ambient air, until weight loss reached equilibrium).

Phase I

Phase I was designed to compare similarities and differences of insecticide residues on fabric specimens after laundering. The effects of fabric finishes on removal tendencies were observed, as were the effects of laundry additives.

Six specimens from each fabric were contaminated with each of the eleven

insecticides. Three of the specimens served as controls, while the other three were subjected to one of three laundry treatments. All work was replicated three times.

Laundry Treatments—The research design included three laundry treatments. Using procedures modified from American Association of Textile Chemists and Colorists (AATCC) standard 61-1980, Colorfastness to Washing, Domestic; and Laundering Commercial Accelerated, the accelerated method was adjusted to simulate a single laundry cycle. A 12-min wash cycle using a 0.2% detergent solution was followed by 5 and 3-min rinses. Agitation was provided by 25 steel balls; all the cycles used 49°C (120°F) distilled water. Teflon liners were placed between the rubber gaskets and the canisters to prevent absorption of pesticide by the gasket [16]. All three laundry treatments² included this standard laundry procedure. The two additional treatments included laundry additives of a prewash spray, or an agriculturally marketed degreaser pretreatment. These laundry pretreatments were applied with the micropipette programmed to deliver 0.225 mL of additive to each specimen.

Phase II

The longevity of the effectiveness of the soil-repellent finishes in limiting sorption of pesticide was analyzed in Phase II of this study. Clean specimens with no functional finish (UN), a renewable consumer-applied fluorocarbon finish (RF), and a commercially applied fluorocarbon finish (CM) were laundered zero through five times prior to contamination using the standard laundry procedure described earlier. All the work was replicated three times. Comparison of contamination levels for the UN, RF, and CM specimens after zero through five launderings determined the useful life of each fluorocarbon finish.

Extraction and Analysis of Pesticide

Each fabric specimen was extracted in 500-mL glass bottles with Teflon-lined lids in two 100-mL aliquots of glass-distilled acetone. Each specimen with solvent was shaken for 1½ h and decanted, the procedure was repeated, and the two aliquots were combined. The acetone extracts were analyzed using a Hewlett-Packard gas chromatograph Model 5850A with automatic injection, and a nitrogen-phosphorus-specific thermionic detector and dedicated microprocessor. All the separation columns used were glass of 2.0 mm inside diameter. Nitrogen was used as a carrier gas. The column tempera-

²Three laundry treatments are to be abbreviated Tx₁, Tx₂, and Tx₃. Tx₁ used Dynamo as a detergent. Tx₂ used Dynamo with Spray 'n Wash, a prewash spray. Tx₃ used Dynamo with Super D, an agriculturally marketed degreaser pretreatment. (Use of registered trade names does not imply endorsement of a specific product.)

tures differed with each chemical (Table 1). All OV columns were packed on Chromasorb W HP; Apiezon L columns were packed on Supelcoport.

Statistical Analysis

The total amount of contaminant in the specimen was expressed in micrograms per square centimetre; these were computed for the eleven pesticides for each of the three fabric finishes (UN, RF, and CM). The data were arc sine converted, and general linear model factorial experiment analysis of variance was performed with a decision level of $P \leq 0.05$. Least significant means tests were performed to determine whether or not differences between pairs of means were significant.

Results and Discussion

The UN specimen retained ten times the pesticide ($26.3 \mu\text{g}/\text{cm}^2$) of the RF ($2.8 \mu\text{g}/\text{cm}^2$) and CM ($2.8 \mu\text{g}/\text{cm}^2$) specimens at initial contamination. The fluorocarbon soil-repellent finishes effectively reduced the hydrophilicity of the specimens so that the liquid pesticide beaded on the surface of the finished fabric and reduced initial contamination (Table 2). There were no sig-

TABLE 1—Column temperatures used in detection by gas chromatography.

Insecticide	Column Temperature, °C	Column Packing
Organophosphates		
Chlorpyrifos	194	3% OV-25
Dichlorvos	152	3% OV-25
Diazinon	180	3% OV-25
Dimethoate	189	3% OV-25
Malathion	196	3% OV-25
Methyl parathion	210	3% OV-25
Carbamates		
Carbofuran	165	5% Apiezon L
Propoxur	170	3% OV-25
Organochlorines		
Aldrin	184 or 197 ^a	3% OV-25
Chlordane	195	5% Apiezon L
Lindane	163 or 193 ^a	1.5% OV-17 + 1.95% 1.95% OV-210

^aTwo column temperatures were used with aldrin and lindane. Because of extreme low residue levels, solvent extracts were evaporated to minute amounts. Interference by coextractions necessitated a lower temperature to achieve peak separation on chromatograms.

TABLE 2—*Residue remaining after laundering, in micrograms per square centimetre.*

Pesticide	Treatment ^a	Residue Remaining on Finish, $\mu\text{g}/\text{cm}^2$		
		UN	RF	CM
Organophosphates Chlorpyrifos	Un ₁	25.61	3.63	3.44
	Tx ₁	6.92	0.94	1.23
	Tx ₂	1.65	0.24	0.93
	Tx ₃	1.07	0.13	0.72
DDVP	Un ₁	18.40	1.46	1.68
	Tx ₁	0.01	0.01	0.01
	Tx ₂	0.01	0.00	0.00
	Tx ₃	0.01	0.00	0.00
Diazinon	Un ₁	24.79	3.66	2.79
	Tx ₁	0.96	0.07	0.05
	Tx ₂	0.25	0.03	0.03
	Tx ₃	0.27	0.03	0.03
Dimethoate	Un ₁	27.60	2.58	2.58
	Tx ₁	0.00	0.00	0.00
	Tx ₂	0.00	0.00	0.00
	Tx ₃	0.00	0.00	0.00
Malathion	Un ₁	26.63	3.10	3.08
	Tx ₁	0.03	0.00	0.00
	Tx ₂	0.02	0.00	0.00
	Tx ₃	0.01	0.00	0.01
Methyl parathion	Un ₁	31.65	4.99	4.45
	Tx ₁	0.15	0.04	0.02
	Tx ₂	0.06	0.01	0.01
	Tx ₃	0.06	0.01	0.03
Carbamates Carbofuran	Un ₁	35.11	2.57	2.48
	Tx ₁	0.05	0.00	0.00
	Tx ₂	0.04	0.00	0.00
	Tx ₃	0.04	0.00	0.00
Propoxur	Un ₁	37.93	5.46	5.33
	Tx ₁	0.03	0.06	0.01
	Tx ₂	0.04	0.00	0.00
	Tx ₃	0.02	0.00	0.00
Organochlorines Aldrin	Un ₁	27.24	2.28	3.12
	Tx ₁	2.48	0.13	0.52
	Tx ₂	1.41	0.08	0.60
	Tx ₃	1.64	0.06	0.65
Chlordane	Un ₁	11.44	0.78	0.79
	Tx ₁	1.96	0.00	0.00
	Tx ₂	0.65	0.00	0.00
	Tx ₃	0.73	0.00	0.00
Lindane	Un ₁	22.86	1.76	2.15
	Tx ₁	0.12	0.05	0.21
	Tx ₂	0.07	0.04	0.12
	Tx ₃	0.13	0.07	0.15
Mean for finishes for the laundered specimens		.63	.06	.16

^aKey to abbreviations:Un₁ = unlaundered.Tx₁ = detergent alone.Tx₂ = detergent with prewash spray.Tx₃ = detergent with agricultural degreaser.

nificant differences in initial contamination based on pesticide ($F = 1.12$; $df = 2,10$). (All references to 0% residue remaining may be interpreted as below the minimum amount detectable with the gas chromatographic analysis used.)

Phase I

Residues After Laundering—Contamination of specimens after laundering was determined for each pesticide and for each fabric finish. Residues after laundering were markedly lower in most instances for fabrics with fluorocarbon finishes (Table 2). Amounts of residue after laundering for dimethoate, dichlorvos, and malathion were at the boundary of detection. Residues for lindane on the CM were slightly higher than residues on the UN.

The means across replication were contrasted to determine the residue remaining after laundering as a percentage of the initial contamination. Pesticide residues after laundering ranged from 0.00 to 35.80% of the initial contamination (Table 3). The residues after laundering expressed as percentages of contamination were not always lower in the fluorocarbon-finished specimens (lindane), indicating that although the finish reduced the sorption of pesticide, these residues were not necessarily easier to remove.

Effect of Pesticide Class—When the pesticides were grouped by class, the interaction between the effect of pesticide class and the fabric finish was significant (Table 4). Because of the statistical significance of this interaction effect, main effects must be examined with caution. Class contributed to differences in residues remaining after laundering (Table 4). Organochlorine (OCI) insecticides were the most difficult to remove, followed by organophosphates (OP) and carbamates (CARB) (Table 5). The residues remaining after laundering for each class were 5.56%, 3.49%, and 0.10% for OCI, OP, and CARB, respectively.

Effect of Finish—The pesticide class-fabric finish interaction significantly affected the percentage of residue remaining after laundering (Table 4). When calculated by averaging across all pesticides (Table 3), the residues remaining for the RF specimen were the smallest (2.03%), followed by the UN (2.89%) and CM (5.27%) specimens. It is important to note that the impact of finish in repelling the pesticide solution, and thus the level of contamination (in micrograms per square centimetre) before laundering of the RF and CM finishes was about one tenth that of the UN (Table 2).

Effect of Laundry Treatment—Although there was no significant interaction between class and laundry treatment in pesticide residues after laundering, there was a trend for differences related to laundering procedures (Table 4). The laundry pretreatments designed to operate as degreasing agents, that is, prewash spray (Tx_2) and agricultural degreaser (Tx_3), worked in similar ways and reduced the percentage of residues remaining following laundering.

TABLE 3—*Percentage of residue remaining after laundering compared with the control fabrics of identical finishes.*

Pesticide	Treatment ^b	Percentage of Residue Remaining on Finish ^a		
		UN	RF	CM
Organophosphates				
Chlorpyrifos	Tx ₁	26.78 ^a	25.76 ^{ac}	35.80 ^d
	Tx ₂	6.41 ^b	6.73 ^b	27.13 ^a
	Tx ₃	4.20 ^b	3.27 ^b	20.95 ^c
Dichlorvos	Tx ₁	0.06 ^c	0.56 ^c	0.73 ^e
	Tx ₂	0.05 ^c	0.75 ^c	0.13 ^e
	Tx ₃	0.03 ^c	0.15 ^c	0.05 ^e
Diazinon	Tx ₁	3.74 ^{fh}	2.06 ^{gh}	1.84 ^{fghi}
	Tx ₂	1.13 ^{ghi}	0.69 ^{ghi}	0.98 ^{ghi}
	Tx ₃	1.07 ^{ghi}	0.66 ^{gi}	1.21 ^{ghi}
Dimethoate	Tx ₁	0.02 ^j	0.00 ^j	0.00 ^j
	Tx ₂	0.02 ^j	0.00 ^j	0.00 ^j
	Tx ₃	0.02 ^j	0.00 ^j	0.00 ^j
Malathion	Tx ₁	0.13 ^k	0.06 ^k	0.02 ^k
	Tx ₂	0.07 ^k	0.05 ^k	0.02 ^k
	Tx ₃	0.07 ^k	0.02 ^k	0.01 ^k
Methyl parathion	Tx ₁	0.51 ^m	0.86 ^m	0.46 ^m
	Tx ₂	0.20 ^m	0.25 ^m	0.30 ^m
	Tx ₃	0.20 ^m	0.24 ^m	0.56 ^m
Carbamates				
Carbofuran	Tx ₁	0.15 ⁿ	0.02 ⁿ	0.00 ⁿ
	Tx ₂	0.10 ⁿ	0.04 ⁿ	0.00 ⁿ
	Tx ₃	0.11 ⁿ	0.02 ⁿ	0.00 ⁿ
Propoxur	Tx ₁	0.08 ^q	1.02 ^r	0.09 ^{pq}
	Tx ₂	0.10 ^q	0.03 ^q	0.00 ^{pq}
	Tx ₃	0.06 ^q	0.04 ^q	0.00 ^{pr}
Organochlorines				
Aldrin	Tx ₁	6.27 st	5.74 st	16.72 ^v
	Tx ₂	5.16 st	3.47 ^{stu}	19.23 ^v
	Tx ₃	6.03 st	2.70 ^{tu}	20.89 ^v
Chlordane	Tx ₁	17.17 ^w	0.00 ^y	0.00 ^y
	Tx ₂	5.67 ^x	0.84 ^y	0.00 ^y
	Tx ₃	6.39 ^x	0.00 ^y	0.00 ^y
Lindane	Tx ₁	0.54 ^z	2.84 ^z	9.64 ^o
	Tx ₂	0.32 ^z	2.44 ^z	5.57 ^a
	Tx ₃	0.58 ^z	4.24 ^a	6.88 ^a
Mean for finishes		2.89	2.03	5.27

^aNumbers within chemicals followed with the same letter were not statistically different at $P \leq 0.05$. UN = unfinished; RF = renewable finish; CM = commercial finish.

^bKey to abbreviations:

Tx₁ = detergent alone.

Tx₂ = detergent with prewash spray.

Tx₃ = detergent with agricultural degreaser.

TABLE 4—ANOVA of the effects of pesticide class, fabric finish, and laundry treatment on the percentage of residue remaining after laundering.

Effect	Degrees of Freedom	F Value	P < 0.05
Pesticide class	2	21.39	...
Fabric finish	2	3.09	...
Treatment	2	2.92	...
Pesticide class by fabric finish	4	2.77	...
Pesticide class by treatment	4	0.48	ns ^a
Finish by treatment	4	0.11	ns
Class by finish by treatment	8	0.10	ns

^ans = not significant.

TABLE 5—Mean residues remaining based on the percentage of contaminant absorbed by fabric of like finish for each pesticide.

Pesticide	Pesticide Class	$\bar{X}$ % of Residue Remaining	LS of Mean Group ^a
Chlorpyrifos	OP	17.50	A
Aldrin	OC1	9.62	B
Lindane	OC1	3.67	C
Chlordane	OC1	3.34	D
Diazinon	OP	1.48	D
Methyl parathion	OP	0.40	E F
Dichlorvos	OP	0.28	E F G
Propoxur	CARB	0.16	F G H
Malathion	OP	0.05	F G H
Carbofuran	CARB	0.05	G H
Dimethoate	OP	0.01	G H

^aLetters indicate statistical similarity.

Across all the pesticides and finishes, the prewash spray was generally more effective than the agricultural degreaser.

Effect of Pesticide (Within Class)—Given the difference between classes in residue removal in laundering and the observation that great variability was observed in the after-laundering residues of the organophosphates, it then became important to ascertain whether differences in removal were attributable to differences within chemical classes. Three-way and two-way ANOVA analyses showed interaction effects for pesticide/fabric finish/laundry treatment ($F = 6.61$; $df = 40$; $P \leq 0.05$) and two-way interaction effects for pesticide/fabric finish ($F = 8.19$; $df = 20$; $P \leq 0.05$), with main effects for pesticide ($F = 245.69$; $df = 10$; $P \leq 0.05$), finish ($F = 27.18$; $df = 2$; $P \leq$

0.05), and laundry treatment ($F = 29.65$; $df = 2$; $P \leq 0.05$). Least-square (LS) means were used to explore these interactions, as they contribute to the main effects. In some cases the residue differences between finishes or laundry treatments were small but substantial enough to make an interaction significant. Such differences are not crucial and may be considered minute for practical purposes. For example, dimethoate residues were near or below a detectable level regardless of the treatment or finish (Table 2). As the residues approached zero, there was little effect attributable to finish or treatment. Interactions that cause a reduction or increase in removal may be indicators of phenomena that should be pursued further.

Scrutiny of the LS means showed that specimens with large percentages of residue remaining after laundering were contaminated with different pesticides; they also were from different treatment groups and frequently of dissimilar finishes. The interaction of the combination of effects may act uniquely for an individual specimen, resulting in differences in residues attributable to no single factor. LS means were used to separate pesticides (Table 5).

Fabric finish played a twofold role in the study. First, it limited initial contamination, and second, it was a facilitator or inhibitor of residue removal during laundering. Pesticide and laundry treatment in combination produced residues after laundering that were specific for the pesticide (Tables 2 and 3).

To make recommendations for protection of agricultural workers, the total contamination, in micrograms per square centimetre, for each pesticide and the toxicity of that pesticide must be examined. By combining the amount absorbed by the fabric, and its tendency for retaining residues, a model can be built from among the variables studied for optimizing protective conditions.

The authors recommend that protocols be established and exceptions noted prior to disseminating recommended procedures for limiting absorption and reducing residues for specific pesticides. The objective of this phase of the study was to determine the effects of several variables on residues remaining after contamination and after laundering. The interactions discussed illustrate inaccuracies that can occur if one laundry treatment is recommended as advantageous for all pesticides or pesticide classes.

Phase II

Longevity of Soil-Repellent Finishes—The pesticide sorption after repeated laundering of the fabrics increased from 25.37 to 31.05 $\mu\text{g}/\text{cm}^2$ for UN, from 5.07 to 17.52, $\mu\text{g}/\text{cm}^2$ for RF, and from 4.57 to 7.80 $\mu\text{g}/\text{cm}^2$ for CM (Fig. 1). The LS means showed no significant difference in pesticide residues for the CM specimens across all the launderings. The CM finish was not significantly affected by five launderings.

FIG. 1—Amount of pesticide residue on fabrics.

The RF finish was effective in reducing absorption through four launderings. After four launderings there were no significant differences between the unlaundered and the laundered specimens. The fifth laundering resulted in a significant difference in pesticide sorption.

Fluorocarbon finishes work significantly better ($F = 363.95$; $P \leq 0.05$) than UN fabrics in limiting sorption of pesticide. Knowledge of longevity of the soil-repellent finishes is necessary for practical understanding of the use of finishes in protective apparel systems. These data showed the amount of pesticide sorbed by the fluorocarbon-finished specimens to be related to the number of launderings to which the fabric has been subjected.

It is not anticipated that a consumer would expect to reapply the CM finish. The garment may no longer be protective after the initial finish is rendered ineffective by repeated launderings or by abrasion during wear. Further work is needed to determine if and when the pesticide repellency of the CM finish decreases significantly.

The RF finish functions effectively through four launderings. At that point reapplication of the finish is recommended to achieve continued protection. By thoroughly reapplying the finish after four launderings, the consumer can be confident that the protective clothing will remain protective for another series of launderings.

Conclusion

To date, recommendations for effective laundering procedures for contaminated clothing have been made regardless of pesticide class and chemical composition. This study was done to establish if laundering recommendations could be made irrespective of chemical class or, if that was not possible, whether appropriate laundering recommendations per class could be established, or if it will be necessary to establish recommendations for individual pesticides.

Differences in the percentage of residue remaining after laundering were found both among and within classes and by finishes. OCI insecticides had the largest percentages of pesticide residue following laundering. Carbamates showed the smallest percentage of pesticide residue. Both fluorocarbon finishes were found to reduce absorption of pesticide by approximately 90%. In most cases the finish did not retard removal of residues by laundering. The RF facilitated reduction of residue most, followed closely by UN fabrics. The CM fabric retained the largest percentage of residue of the three fabric finishes; this was attributed especially to the persistence of the OCI.

As a result of this study, no specific recommendations based on class should be made. Although removal is related to pesticide class, which has practical implications to the consumer, there is no predominant trend for differences in removal based on class. Water solubility of the active ingredient may be a more reliable indicator of the relative ease of removal than chemical class.

The residues, expressed in micrograms per square centimetre, were less for fabrics with fluorocarbon finishes. The micrograms per square centimetre were slightly lower for the RF than for the CM in some cases. The laundry pretreatments also aided in residue reduction. The prewash spray was slightly more effective than the agriculturally marketed product.

Phase II showed that the amount of pesticide absorbed by the fluorocarbon-finished fabrics was inversely related to the number of launderings to which the specimen has been subjected prior to contamination with pesticide. The CM was not affected by five machine launderings. The RF functioned effectively through four launderings. The authors recommend that the finish be reapplied after four wash cycles to achieve continued protection. Although the CM finish remained effective longer than the RF, recommending it over the RF is questionable. This study did not determine how long the CM would remain effective. In recommending the nonrenewable CM, one cannot predict performance beyond five launderings; therefore, until the outer limits for effective functioning of the CM can be established over a greater number of launderings, the RF is recommended. The recommendations of the RF for protection are accompanied by suggestions to reapply the finish at a minimum rate of 0.80% dry weight gain. This study did not incorporate the effects of abrasion, sunlight, heat, and other variables on the finishes; therefore, renewal of the finish should occur at least after every fourth laundering. This

study did not examine whether or not the soil-repellent treatment does make subsequent pesticide soil more difficult to remove by laundering. Such a study is suggested.

The implications from these findings must be added to previous recommendations. Previous studies have suggested multiple launderings of contaminated garments in large water volumes at hot temperatures of 60°C (140°F). Few items per load, as recommended by Easley et al [3] in "Laundering Pesticide Contaminated Clothing," will also reduce contamination levels. Large water volumes limit pesticide transfer to other items and to the laundering apparatus. Heavy-duty liquid detergent has been recommended as the detergent of choice in previous studies [11, 12]. Additional consumer recommendations based on results of this study include the use of a renewable fluorocarbon-finished fabric and the use of a laundry pretreatment before laundering.

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