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Use of Engineering Controls and Personal Protective Equipment by Certified Pesticide Applicators

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Abstract

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Keywords

Engineering controls, Personal protective equipment, Pesticide applicators, Pesticide handlers, Worker protection standard

Disciplines

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Comments

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Use of pesticides in crop production introduces occupational hazards and health risks to personnel involved in pesticide handling tasks. The adoption of appropriate engineering controls and the proper use of personal protective equipment (PPE) are established strategies for reducing pesticide exposure. Although the efficacy of these strategies is affected by work practices (Kline et al., 2003), human factors (Branson et al., 1988), and personal attitudes (Rucker et al., 1988), these

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variables were not investigated. This survey of certified pesticide applicators in three states focused on the use of engineering controls and the use of PPE.

Human exposure and equipment contamination during pesticide tasks are well documented. Pesticide handlers are at particularly high risk of exposure during mixing and loading tasks, when splashes are most likely (Dubelman et al., 1982; Lavy et al., 1983; Grover et al., 1988). Risk of pesticide exposure is also high when using backpack sprayers (Lavy et al., 1983; Abbott et al., 1987) or airblast sprayers (Keeble et al., 1987; Fenske et al., 1987, Coffman et al., 1999).

Concern for worker safety has led to the modification of pesticide application equipment and to the development of engineering devices that most researchers consider to be the preferred method of reducing handlers' exposure to pesticides (Nielsen and Moraski, 1986; Plog, 1996; Fenske et al., 2002). Derksen et al. (1999) noted that hooded sprayers reduced operator dermal exposure while providing the equivalent pest control obtained during airblast applications. Nigg et al. (1990) found that a canopied (roof only) tractor provided some protection for the driver's upper body when it was used to pull an airblast sprayer. Enclosed cabs have been shown to reduce operator dermal exposure when compared to open-air tractors (Abbott et al., 1987; Lunchick et al., 1988).

Air-filtering systems, added to enclosed tractors cabs, also provide respiratory protection for the pesticide applicator. The American National Standards Institute (ANSI), in cooperation with the American Society of Agricultural and Biological Engineers (ASABE), has published and revised performance criteria, testing procedures, and advisory definitions for these tractor cabs (*ASABE Standards*, 2006). Nonetheless, the efficacy and maintenance of enclosed tractor cabs continue to be of concern to the agricultural and research communities (Fong, 2003; Kline et al., 2003). Kline et al. (2003) found measurable amounts of pesticides inside the tractor cab after a season of spraying.

Closed transfer systems may differ in structure, but all allow pesticides to be transferred directly from the container into the sprayer via a closed route (Fong, 2003). The California Code of Regulations (CDPR, 2009) requires employers to provide employees with closed transfer systems for transferring Toxicity Class One pesticides and rinse solutions. The number of pesticide-related illnesses among mixer/loader workers in California decreased by 50% after the introduction of closed transfer systems (Brazelton and Akesson, 1987).

Although other engineering controls are familiar to the agricultural community and widely available (Landers et al., 2000), few studies have addressed their efficacy in reducing pesticide exposure. The use of induction bowls, container rinse systems, diaphragm check valves, hydraulic folding booms, multiple nozzle bodies, low-drift nozzles, air-induction nozzles, and tank rinse systems has not been fully investigated. Common sense, however, suggests that human exposure could be reduced by using mechanical devices that decrease direct contact with pesticides. Nonetheless, spray equipment manufacturers offer most engineering controls as optional, not standard, equipment, as reported by Landers et al. (2000) in a ten-state survey.

Personal protective equipment (PPE), clothing and devices worn by the worker/handler, is the primary method of reducing human exposure to pesticides. PPE is required as stated on the pesticide label and as detailed in Part 170 of the Worker Protection Standard (WPS) for agricultural pesticides (USEPA, 1992). Clothing made of barrier and non-barrier textiles has been shown to reduce the dermal exposure of workers to pesticides (Laughlin et al., 1986; Easter and Nigg, 1992; Welch and Obendorf, 1997; Lee and Obendorf, 2005; Hughes et al., 2005). Clothing systems ranging from regular work clothes with rubber gloves and boots to totally encapsulated suits are used depending on the pesticide toxicity and the exposure situation. Despite the widespread use of protective clothing, it does not always provide sufficient protection (Fenske et al., 2002), and compliance has not been complete due to the obvious disadvantages of heat stress, limited mobility and dexterity, availability, and cost.

Engineering controls can provide adequate levels of protection for the operator with reduced but appropriate PPE and create more efficient, comfortable working conditions than traditional PPE alone. As early as 1986, Nielsen and Moraski noted that exposure monitoring efforts emphasized the value of both PPE and engineering controls. Indeed, the WPS allows an agricultural pesticide handler to omit some of the label-required PPE when using closed transfer systems or enclosed cabs (USEPA, 1992). The California Department of Pesticide Regulation (CDPR, 2002), Kline et al. (2003), and the *ASABE Standards* (2006) noted the interaction of PPE and engineering controls in the donning, doffing, and storing protocols for PPE when using enclosed cabs for pesticide applications.

The objectives of this study were to examine the current level of use of engineering controls and PPE among a variety of pesticide users, to identify the factors that influence their adoption of engineering controls, and to explore the relationships between their use of engineering controls and use of PPE.

Methods

Questionnaire Development

A questionnaire was drafted by a team of engineers, textile specialists, certified pesticide applicators, pesticide applicator training staff, representatives from commodity associations, and a survey instrument designer. This initial questionnaire was pilot-tested in a telephone survey of 19 certified pesticide applicators by the Computer-Assisted Survey Team (CAST), School of Industrial and Labor Relations, Cornell University (now known as the Survey Research Institute at Cornell). Individual responses were collected, analyzed, and used to design the final two-page questionnaire. Sixteen different engineering controls, eight types of pesticide application equipment and thirteen PPE categories were selected for inclusion in the survey. The questionnaire and collection procedures were approved by the Institutional Review Board for Human Participants at the three participating universities.

Data Collection

Survey data were collected in 2001-2003 from private and commercial certified pesticide applicators through four venues:

- Pesticide applicator training (PAT) sessions in Iowa, Michigan, and New York.
- A large agricultural company in Iowa.
- Exhibit/poster sessions at agricultural conferences in New York and Michigan.
- A mailing to members of the New York State Vegetable Growers Association.

Collection sites were chosen for convenience with attention to the diversity of agriculture and of geographic location. A general invitation to participate in the survey was issued to all certified pesticide applicators in attendance at the collection sites or in receipt of the mailing. No reward or payment was offered.

Persons who volunteered to participate were provided a description of the project, illustrations and written explanations of the engineering controls listed in the questionnaire, illustrations and written explanations of the PPE listed in the questionnaire, contact information of the in-state investigators, and the questionnaire. An investigator or a PAT educator was available to answer questions and to collect the completed questionnaires, except in the case of the New York State Vegetable Growers Association members. The New York vegetable growers received the questionnaire and attendant materials as enclosures in their association newsletter and were provided an addressed stamped envelope for returning the questionnaire. All completed questionnaires were mailed to Cornell University for compilation and analysis.

Sample

A total of 722 certified pesticide applicators participated in the study. Twenty participants were excluded from the analysis because they were either under age 21 (*n* = 15), worked on organic farms (*n* = 2), or answered too few questions (*n* = 3). Data analysis included 702 questionnaires: 137 from New York, 247 from Iowa, and 318 from Michigan. All respondents were anonymous volunteers. Gender data were not collected. Participation rates were not calculated because the denominator could not be determined given the recruitment process. Questionnaires were not made available to all certified applicators in any of the three states.

The convenience sampling of the certified private and commercial pesticide applicators at selected venues from only three states creates limitations on the application of these findings. The results of this study therefore should not be considered representative of all certified private and commercial pesticide applicators in the nation. The results are also not necessarily representative of the three states participating in the study. The study does provide pilot results useful for guiding researchers on the current level of use of engineering controls and PPE, factors that may influence adoption of engineering controls, and relationships between the use of engineering controls and PPE.

Statistical Analysis

Responses to the questionnaires were tabulated and analyzed. Frequencies and percentages were calculated for each variable. Cross-tabulations were used to compare data, and chi-square tests were used for assessment of associations between discrete variables. In order to control type 1 error rate, all p values were Bonferroni adjusted using a single-step adjustment (Kutner et al., 2004). Even when statistically significant, results were interpreted with caution when expected counts in cells were small since chi-square tends to overestimate the significance level of differences (Field, 2000). A logistic regression model was used to assess the association of several independent variables simultaneously on the reduction of PPE use. All statistical analyses were conducted using SPSS (version 14, SPSS, Inc., Chicago, Ill.) with an alpha of 0.05.

Results and Discussion

Unless otherwise stated, results are reported for the total sample of respondents (*n* = 702). As many as 363 respondents did not answer all parts of the questionnaire, creating a reduced sample size for some responses. Categories for respondent's age, years of pesticide application experience, and size of agricultural operation were developed from the actual data reported. Educational categories in the questionnaire were collapsed for this article.

Characteristics of Respondents

After exclusion, all respondents were eligible to be certified pesticide applicators 21 years of age and older. Table 1 shows that almost twice as many were owner/employers (63%) as were employees (35%). A similar relationship existed among the pesticide application certification categories, with 61% of the respondents holding private certification and 34% holding commercial certification. Pesticide application experience was highly correlated linearly (r = 0.689) with the age of the respondent. More than 70% of the responding pesticide applicators were older than 40 years of age and had more than 10 years of experience. All respondents had at least a high school diploma, with 51% reporting some college/college degree and 5% reporting an advanced/professional degree.

From seven types of crops listed on the questionnaire, respondents were asked to identify one or two main crops that they grew or sprayed. If they did not grow or spray any of the listed crops, they were instructed to specify the main crop that they did grow or spray. Livestock operations were not included. Figure 1 illustrates that the majority of respondents grew field crops (67%), followed by vegetables (19%) and tree fruit (10%). The size of the agricultural operation owned by the respondent or for which the respondent worked is shown in figure 2.

Respondents were asked to select all types of pesticide application equipment that they used. If they used a sprayer that was not among the eight listed on the questionnaire, they were instructed to name and describe the equipment. The most commonly used types of pesticide application equipment (fig. 3) were boom sprayers (85%), hand-operated sprayers (36%) and airblast sprayers (15%). Figure 3 shows the distribution of all equipment; it does not quantify the respondents' use of individual sprayers. If respondents used more than one type of sprayer, we could not discern whether

Table 1. Characteristics of pesticide applicators (*n* = 702).

		Total (%)[a]
Employment status	Owner/employer	63
	Employee	35
	Crop advisor	3
Pesticide application certification	Private	61
	Commercial	34
	None[b]	5
Pesticide application experience	<5 years	12
	5-10 years	17
	11-15 years	11
	16-20 years	14
	>20 years	45
Age of pesticide applicators	<30 years	10
	30-40 years	19
	41-50 years	29
	>50 years	43
Education of pesticide applicators	High school	45
	Some college and college degree	51
	Advanced/professional degree	5

[a] Totals may be more or less than 100% because numbers are reported using significant figures.
[b] This category represents first-time participant in certification training, those who failed earlier certification, or those working directly for a certified pesticide applicator.

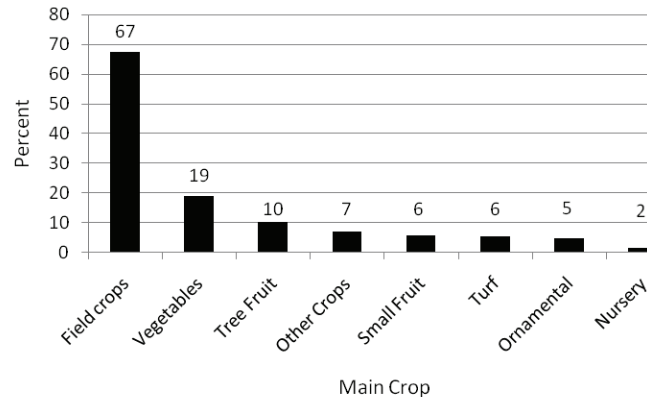

Figure 1. Main crops identified by 702 participants (participants were able to select multiple crops).

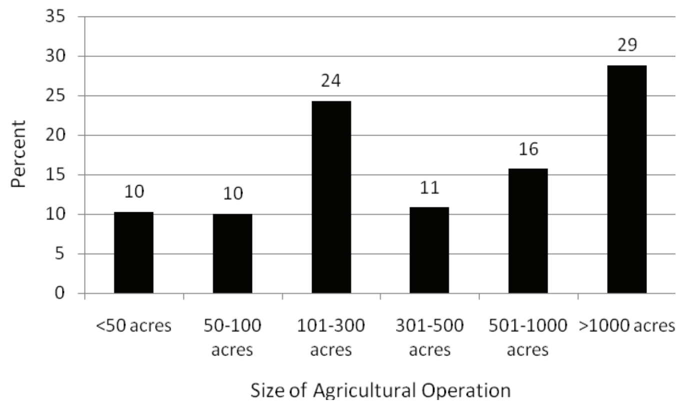

Figure 2. Size of agricultural operation identified by 572 participants.

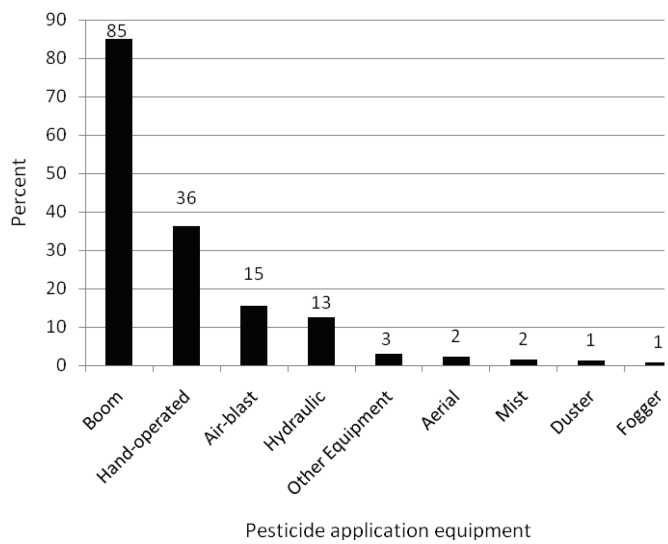

Figure 3. Pesticide application equipment used by 702 participants (participants were able to select multiple types of pesticide application equipment).

one type was used more frequently, only for particular pesticides, or only for particular crops. In addition, some confusion in terminology arose due to regional differences in equipment terms and to the breadth of sprayer design. For example, a vertical boom sprayer might logically be defined as either a boom sprayer or a hydraulic sprayer.

Use of Engineering Controls and Relationships to Other Variables

Sixteen engineering controls were grouped on the questionnaire, and in this article, according to their function and listed in the approximate order of use within the pesticide application process. For example, closed transfer systems, direct pesticide injection, inductions bowls, and container rinse systems help reduce direct contact with the pesticide during mixing and loading. Spray drift during pesticide application can be decreased by using diaphragm check valves, hydraulic folding booms, pulley/cable folding booms, air-assisted folding booms, multiple nozzle bodies, low-drift nozzles, and air-induction nozzles. Exposure due to contaminated surfaces can be lessened by using enclosed tractor cabs, carbon cab filters, protective clothing lockers, and hand wash water supply. Tank rinse systems lower pesticide exposure during cleaning tasks. Figure 4 shows that the most commonly used engineering controls were enclosed tractor cabs (72%), low-drift nozzles (71%), and hand wash water supply (64%). For loading devices, closed transfer systems and induction bowls were each used more than twice as often as direct pesticide injection systems. Among the boom folding/extending devices, hydraulic folding booms were most frequently reported. For controlling drift, low-drift nozzles outranked air-induction nozzles by more than three-fold.

Eight out of the 16 engineering controls were used by more than half of the respondents (fig. 4). This result shows greater use of engineering controls than the findings of Landers et al. (2000), who reported that closed transfer systems, induction systems,

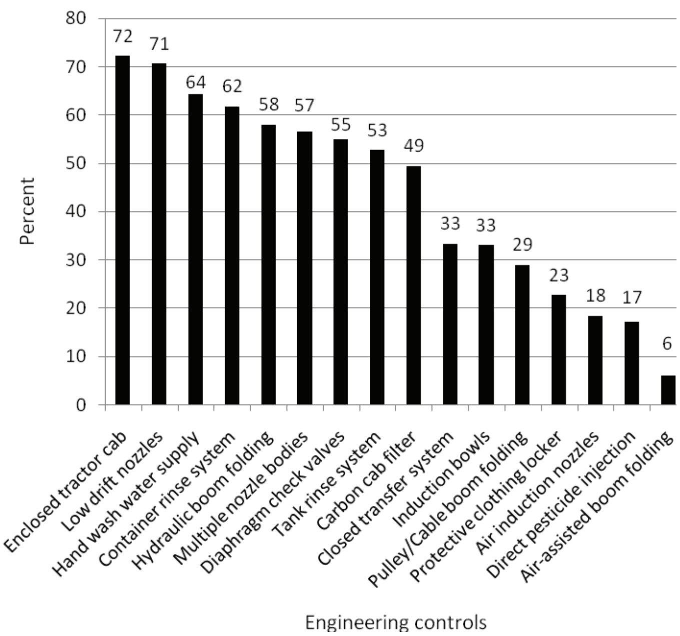

Figure 4. Use of engineering controls identified by 702 participants (participants were able to select multiple engineering controls).

Table 2. Use of engineering controls in relation to field crops and vegetables.

Engineering Controls (n)		Field Crops Yes, n (%)	Field Crops No, n (%)	Field Crops χ^2 (p[a])	Vegetables Yes, n (%)	Vegetables No, n (%)	Vegetables χ^2 (p[a])
Closed transfer system (478)	Yes	141 (40.7)	23 (17.7)	21.87	21 (23.6)	143 (36.8)	5.57
	No	207	107	(<0.001)	68	246	(0.144)
Direct pesticide injection (482)	Yes	64 (19.1)	19 (12.9)	2.73	10 (11.9)	73 (18.3)	2.016
	No	271	128	(0.784)	74	325	(0.99)
Induction bowls (454)	Yes	146 (43.3)	12 (10.3)	41.85	26 (32.9)	132 (35.2)	0.151
	No	191	105	(<0.001)	53	243	(0.99)
Container rinse system (518)	Yes	241 (67.7)	78 (48.1)	17.98	51 (52.0)	268 (63.8)	4.652
	No	115	84	(<0.001	47	152	(0.248)
Diaphragm check valves (491)	Yes	210 (60.7)	60 (41.4)	15.40	40 (46.0)	230 (56.9)	3.47
	No	136	85	(<0.001)	47	174	(0.496)
Hydraulic folding boom (500)	Yes	239 (64.2)	71 (55.5)	3.11	68 (65.4)	242 (61.1)	0.638
	No	133	57	(0.624)	36	154	(0.99)
Pulley/cable folding boom (438)	Yes	117 (35.2)	19 (17.9)	11.25	22 (27.2)	114 (31.9)	0.702
	No	215	87	(0.008)	59	243	(0.99)
Air-assisted folding boom (414)	Yes	19 (6.1)	6 (5.9)	0.006	8 (10.3)	17 (5.1)	3.01
	No	293	96	(0.99)	70	19	(0.64)
Multiple nozzle bodies (509)	Yes	220 (61.8)	68 (44.4)	13.11	53 (53.5)	235 (57.3)	0.464
	No	136	85	(0.00)	46	175	(0.99)
Low-drift nozzles (553)	Yes	287 (74.9)	103 (60.6)	11.65	58 (54.2)	332 (74.4)	16.99
	No	96	67	(0.008)	49	114	(<0.001)
Air-induction nozzles (476)	Yes	76 (22.5)	12 (8.7)	12.36	17 (20.7)	71 (18.0)	0.331
	No	262	126	(<0.001)	65	323	(0.99)
Enclosed tractor cab (539)	Yes	308 (80.4)	90 (57.7)	29.63	66 (62.3)	332 (76.7)	9.15
	No	75	66	(<0.001)	40	101	(0.016)
Carbon cab filter (497)	Yes	198 (55.8)	56 (39.4)	10.83	46 (48.4)	208 (51.7)	0.339
	No	157	86	(0.008)	49	194	(0.99
Protective clothing locker (462)	Yes	91 (27.1)	17 (13.5)	9.45	18 (20.9)	90 (23.9)	0.353
	No	245	109	(0.016)	68	286	(0.99)
Hand wash water supply (529)	Yes	282 (72.9)	65 (45.8)	33.79	58 (57.4)	289 (67.5)	3.69
	No	105	77	(<0.001)	43	139	(0.44)
Tank rinse system (533)	Yes	232 (61.2)	48 (31.2)	39.64	38 (38.8)	242 (55.6)	9.11
	No	147	106	(<0.001)	60	192	(0.024)

[a] Bonferroni adjusted p-value.

tractor cabs with carbon filtration, and tank rinsing systems were found on no more than 25% of the farms visited by their respondents. Some differences between the findings of these two studies may be attributed to the distinct samples. Respondents in the study by Landers et al. (2000) were application equipment manufacturers, state pesticide regulators, PAT coordinators, and state pesticide enforcement agents who reported their observations, while respondents in this study reported on actual field use. In addition, the study by Landers et al. (2000) included 215 respondents from ten states, one state from each USEPA region, while this study included respondents from only three states. New York was the only state common to both studies.

Factors that influenced the adoption of engineering controls in this study were the type of crops grown, the size of the agricultural operation, and the type of pesticide application equipment used. Field crop growers had significantly higher use of most engineering controls than other respondents (table 2). Furthermore, vegetable growers showed significantly lower use of low-drift nozzles, enclosed tractor cabs, and tank

Table 3. Use of engineering controls in relation to size of operation.

Engineering Controls (n)		Size of Operation (acres) <50	51-100	101-300	301-500	501-1000	>1000	χ^2	p[a]
Closed transfer systems (393)	Yes	4	2	15	7	18	73	55.19	<0.001
	No	27	28	74	34	42	69		
Direct pesticide injection (390)	Yes	5	1	4	3	7	34	23.11	0.005
	No	33	29	78	38	50	108		
Induction bowls (371)	Yes	3	0	10	9	15	85	91.84	<0.001
	No	26	23	69	33	42	56		
Container rinse system (424)	Yes	20	15	51	23	46	104	15.38	0.141
	No	17	20	44	19	20	45		
Diaphragm check valves (397)	Yes	13	11	37	23	34	92	20.94	0.013
	No	23	18	54	17	24	51		
Hydraulic folding boom (408)	Yes	12	12	42	18	27	127	76.59	<0.001
	No	12	18	53	27	38	22		
Pulley/cable folding boom (357)	Yes	6	8	26	9	14	48	3.89	0.99
	No	15	18	58	31	40	84		
Air-assisted folding boom (339)	Yes	0	0	3	2	2	10	6.76	0.99
	No	20	23	76	35	51	117		
Multiple nozzle bodies (416)	Yes	19	12	40	16	27	108	41.23	<0.001
	No	19	19	58	26	34	38		
Low-drift nozzles (453)	Yes	24	25	62	34	52	124	26.06	<0.001
	No	20	14	43	14	16	25		
Air-induction nozzles (386)	Yes	3	1	6	3	8	49	45.91	<0.001
	No	33	29	79	39	47	89		
Enclosed tractor cab (447)	Yes	18	17	72	32	51	138	55.28	<0.001
	No	18	18	37	18	15	13		
Carbon cab Filter (407)	Yes	9	11	38	7	17	112	82.65	<0.001
	No	22	22	60	34	39	36		
Protective clothing locker (378)	Yes	4	3	14	6	11	45	15.87	0.115
	No	25	26	72	35	45	92		
Hand wash water supply (435)	Yes	11	14	47	24	48	127	67.78	<0.001
	No	21	21	56	23	18	25		
Tank rinse system (433)	Yes	13	14	44	14	35	97	25.45	0.002
	No	23	24	55	30	30	54		

[a] Bonferroni adjusted p-value.

rinse systems as compared to all other respondents. Not included in the table, tree fruit and small fruit growers showed significantly lower use of closed transfer systems, induction bowls, hand wash water supply, and tank rinse systems. Turf and ornamental growers showed significantly lower use of hydraulic folding booms, enclosed tractor cabs, carbon cab filters, and hand wash water supply.

A significant relationship was found between the size of operation and the use of most engineering controls (table 3). In general, adoption of engineering controls increased with the size of operation. Some engineering controls, such as the hand wash water supply, demonstrated a continuous upward trend. A close examination of the observed and expected counts in the cross-tabulation tables showed that 1000 acres was the statistically significant threshold for obtaining closed transfer systems, induction bowls, hydraulic folding booms, multiple nozzle bodies, air-induction nozzles, and carbon cab filters. This finding is consistent with observations reported by state pesticide inspectors, who noted that farm operations of 1001 acres or larger would most likely adopt closed transfer systems, chemical induction systems, and cabs with carbon filtration (Landers et al., 2000).

Table 4. Use of engineering controls in relation to boom and hydraulic sprayers.

Engineering Controls (*n*)		Boom Sprayer Yes, *n* (%)	Boom Sprayer No, *n* (%)	Boom Sprayer χ^2 (p[a])	Hydraulic Sprayer Yes, *n* (%)	Hydraulic Sprayer No, *n* (%)	Hydraulic Sprayer χ^2 (p[a])
Closed transfer system (478)	Yes	159 (35.4)	5 (17.2)	3.991	38 (50.7)	126 (31.3)	10.56
	No	290	24	(0.368)	37	277	(0.008)
Direct pesticide injection (482)	Yes	74 (17.2)	9 (17.3)	0.001	16 (22.5)	67 (16.3)	1.650
	No	356	43	(0.99)	55	344	(0.99)
Induction bowls (454)	Yes	155 (36.3)	3 (11.1)	7.101	32 (43.2)	126 (33.2)	2.777
	No	272	24	(0.064)	42	254	(0.768)
Container rinse system (518)	Yes	293 (63.1)	26 (48.1)	4.599	57 (74.0)	262 (59.4)	5.919
	No	171	28	(0.256)	20	179	(0.12)
Diaphragm check valves (491)	Yes	255 (58.1)	15 (28.8)	16.06	44 (62.9)	226 (53.7)	2.042
	No	184	37	(<0.001)	26	195	(0.99)
Hydraulic folding boom (500)	Yes	304 (62.3)	3 (22.6)	0.751	64 (83.1)	246 (58.2)	17.227
	No	184	9	(0.99)	13	177	(<0.001)
Pulley/cable folding boom (438)	Yes	136 (31.9)	0 (0.0)	5.556	26 (36.1)	110 (30.1)	1.031
	No	290	12	(0.144)	46	256	(0.99)
Air-assisted folding boom (414)	Yes	24 (6.0)	1 (8.3)	0.115	10 (14.5)	15 (4.3)	10.43
	No	378	11	(0.99)	59	330	(0.008)
Multiple nozzle bodies (509)	Yes	270 (59.3)	18 (33.3)	13.29	50 (70.4)	238 (54.3)	6.434
	No	185	36	(<0.001)	21	200	(0.088)
Low-drift nozzles (553)	Yes	357 (72.9)	33 (52.4)	11.25	59 (77.6)	331 (69.4)	2.141
	No	133	30	(0.008)	17	146	(0.99)
Air-induction nozzles (476)	Yes	86 (20.2)	2 (4.0)	7.781	22 (30.1)	66 (16.4)	7.765
	No	340	48	(0.04)	51	337	(0.04)
Enclosed tractor cab (539)	Yes	380 (75.2)	18 (52.9)	8.206	64 (83.1)	334 (72.3)	4.002
	No	125	16	(0.032)	13	128	(0.36)
Carbon cab filter (497)	Yes	239 (51.6)	15 (44.1)	0.713	57 (75.0)	197 (46.8)	20.498
	No	224	19	(0.99)	19	224	(<0.001)
Protective clothing locker (462)	Yes	102 (23.5)	6 (21.4)	0.063	27 (38.0)	81 (20.7)	10.054
	No	332	22	(0.99)	44	310	(0.016)
Hand wash water supply (529)	Yes	339 (67.7)	8 (28.6)	17.958	55 (74.3)	292 (64.2)	2.905
	No	162	20	(<0.001)	19	163	(0.704)
Tank rinse system (533)	Yes	260 (54.3)	20 (37.0)	5.786	55 (72.4)	225 (49.2)	13.986
	No	219	34	(0.128)	21	232	(<0.001)

[a] Bonferroni adjusted p-value.

PPE and Relationships to Engineering Controls

The personal protective equipment (PPE) and regular work clothes usually worn by the survey respondents when handling pesticides are shown in figure 5. The 13 clothing categories were presented in a logical order from body, hand, feet, head, eye, to respiratory protection. Participants were allowed to select all PPE worn; thus, some respondents reported using more than one type of garment within a category. For example, some respondents reported using only one type of respirator, while others reported wearing two or three types. Furthermore, the data cannot be interpreted to show which PPE is worn with which application equipment because a respondent could report more than one type of each.

The most commonly worn PPE was chemical-resistant gloves (79.9%), followed by safety glasses (48.9%) and hats with wide brims (47.6%). Previous research has shown that hands are the most exposed part of the body (Lavy et al., 1983; Reinert and Severn, 1985; Grover et al., 1988; Sanderson et al., 1995) and that proper use of chemical-

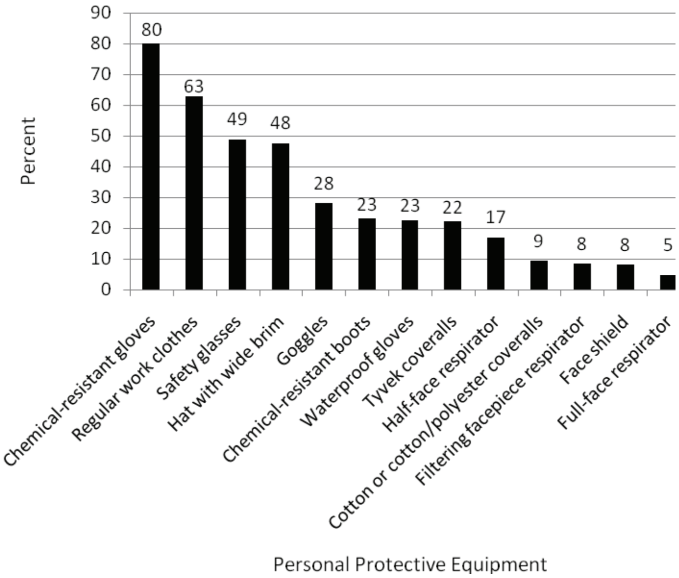

Figure 5. Personal protective equipment worn by 702 participants (participants were able to select multiple personal protective equipment).

resistant gloves reduces this exposure (Fenske et al., 1987; Schwope et al., 1992). Results from this survey are consistent with those of earlier PPE surveys in which the highest rate of compliance with PPE requirements has been in the wearing of chemical-resistant gloves (Stone et al., 1994; Partridge et al., 1995; Weingart et al., 1996, Hines et al., 2007).

Among the different types of eye protection, safety glasses were the most commonly used, followed by goggles and face shields. Surveys conducted prior to the implementation of the Worker Protection Standard (USEPA 1992) only record the use of goggles (Keeble et al., 1987). The data from our survey were similar to those of post-WPS surveys (Stone et al., 1994; Partridge el al., 1995; Weingart et al., 1996).

The USEPA (1992) recommends that pesticide applicators wear a chemical-resistant hood or a hat with a wide brim made of rubber, plastic, or a chemical-resistant material in the "safari" or "firefighter" styles. Almost half of the respondents reported wearing a hat with a wide brim. This finding is a significant increase in the use of recommended headgear compared to earlier surveys by Keeble et al., 1987 (2.6%), Rucker et al., 1988 (3%), and Partridge et al., 1995 (18.9%) and an important change from the five-state survey by Rucker et al. (1988) in which 70% of 1614 farmers reported wearing baseball-style caps. To be certain that the respondents understood that the hat with wide brim category did not include baseball-style caps, illustrations of PPE including appropriate hat styles were distributed with the questionnaires, and the on-site educator mentioned this during the project explanation.

Relationships between the use of engineering controls and the use of PPE items were examined. Table 5 lists the nine engineering controls that showed a significant difference in the wearing of PPE between respondents who did and those who did not use engineering controls. For example, 41.1% of the 158 respondents who used induc-

Table 5. Use of engineering controls in relation to PPE.

Engineering Control		PPE			
Type (*n*)	Use (*n*)	Type	Use (%)	χ^2	p[a]
Induction bowls (454)	Yes: 158 No: 296	Safety glasses	41.1 58.1	11.88	0.015
Direct pesticide injection (482)	Yes: 83 No: 399	Chemical-resistant gloves	96.4 83.7	9.11	0.045
Hydraulic folding boom (500)	Yes: 310 No: 190	Safety glasses	45.2 60.0	10.37	0.015
Multiple nozzle bodies (509)	Yes: 288 No: 221	Chemical-resistant gloves	91.7 79.2	16.42	<0.001
Hand wash water supply (529)	Yes: 347 No: 182	Cotton or cotton/ polyester coveralls	7.2 15.9	9.92	0.030
		Half-face respirator	13.5 25.8	12.32	<0.001
Carbon cab filter (497)	Yes: 254 No: 243	Chemical-resistant gloves	90.9 80.7	10.85	0.015
		Safety glasses	44.5 59.3	10.85	0.015
Enclosed tractor cab (539)	Yes: 398 No: 141	Chemical-resistant gloves	88.2 75.2	13.67	<0.001
		Half-face respirator	14.1 29.1	15.89	<0.001
Protective clothing locker (462)	Yes: 108 No: 354	Regular work clothes	54.6 72.3	11.93	0.015
		Tyvek coveralls	36.1 21.5	9.49	0.030
Tank rinse system (533)	Yes: 280 No: 253	Chemical-resistant gloves	89.6 80.6	8.63	0.045

[a] Bonferroni adjusted p-value.

tion bowls wore safety glasses, while 58.1% of the 296 respondents who did not use induction bowls wore safety glasses. Use of half-face respirators and safety glasses was lower for respondents who used some types of engineering controls than for those who used no engineering controls. In contrast, a significant number of pesticide applicators reported higher use of chemical-resistant gloves when using engineering controls. Hines et al. (2007) noted that among pesticide applicators using airblast sprayers, those who used enclosed cabs were less likely to wear respirators (5.6%) and rubber gloves (0%) than those without enclosed cabs (60.7% and 65.6%, respectively).

To further explore the influence of using engineering controls on PPE selection and use, respondents were asked whether they deliberately wear less PPE because they have engineering controls and, if so, what PPE do they omit. Most of the respondents (87.3% of the 702 respondents) reported that they do not wear less PPE because they use engineering controls. Some respondents volunteered that they always wear the label-recommended PPE or that they simply like to maintain a routine. Others doubted the efficacy of engineering controls alone or found the WPS exceptions too complicated to remember.

A small portion (12.7% of the 702 respondents) reported wearing less PPE when using engineering controls and listed coveralls, respirators, gloves, boots, face shields, and safety glasses as the items they omit. To better describe this 12.7% of respondents, logistic regression was performed to determine whether any variables were associated with self-reported less use of PPE when using engineering controls (yes/no). The variables tested in the logistic multivariate regression model (Kleinbaum et al., 2007) included age, education, application experience, size of agricultural operation, main crops (i.e., field crops, small fruits, turf, tree fruit, ornamental, nursery, vegetables), pesticide application equipment, and engineering controls. Both forward and backward stepwise selection was used, with the final model being refined using a non-automated method with a level of significance of 0.05. Only the variables that were significant in relation to reduction in PPE were kept in the final model. The two variables that were statistically significant were vegetables growers and enclosed tractor cab. Being a vegetable grower versus not being a vegetable grower increased the odds of using less PPE by a factor of 3.15 ($p < 0.001$). Being a user of an enclosed tractor cab versus not being a user resulted in a decrease in odds of using less PPE by 0.781 ($p < 0.001$).

Worker Protection Standard 40 CFR part 170.240 allows reduction or substitution of label-required PPE provided that certain conditions and requirements are met, such as when handling tasks are performed from inside an enclosed cab, when closed transfer systems are used, and during aerial applications (USEPA, 1992). The survey results, however, did not include sufficient data to ascertain whether the respondents who modified their PPE because they used enclosed cabs were in compliance with the WPS.

Educational Resource Preferences

Pesticide applicators were asked if they needed more information on what PPE is required when using different types of pesticide application equipment. Only 25% said that they needed more information.

Respondents also were asked to identify the types of educational resources they would be most likely to use. The most preferred educational resource was workshops (57%), followed by training manuals (50%), farm/crop magazines (42%), brochures (33%), and videotapes (23%). The low interest (17%) in using the internet indicates the need for non-electronic resources and/or the need for more instruction in how to access information on the internet.

Summary and Conclusions

The convenience sampling of the certified private and commercial pesticide applicators at selected venues from three states limits the application of these findings. The conclusions of this study therefore should not be considered representative of all certified private and commercial pesticide applicators in the nation. The conclusions are also not necessarily representative of the three states participating in the study.

Both engineering controls and personal protective equipment are important control measures to reduce pesticide users' exposure to pesticides. More than 50% of the respondents in this survey used a container rinse system, diaphragm check valves, hydraulic folding booms, multiple nozzle bodies, low-drift nozzles, enclosed tractor cab, hand wash water supply, and tank rinse system. The primary factors that influenced the adoption of engineering controls were the type of crops grown, the size of the agricultural operation, and the type of pesticide application equipment used. Generally, higher use of engineering devices was reported by growers of field crops, applicators on larger farms, and users of boom and hydraulic sprayers.

The most commonly worn PPE was chemical-resistant gloves (80%), followed by safety glasses (49%) and hats with wide brims (48%). Compared to earlier studies, compliance with label-required PPE has improved steadily over the last two decades. The use of hats with wide brims has increased significantly.

The majority of respondents do not wear less PPE simply because they have engineering controls. Those who did modify their PPE choices used tractors with enclosed cabs and/or were vegetable growers.

As engineering controls and PPE choices change with innovations and policies, the relationship between these two protective strategies is an area of potential research and educational opportunities.

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