Comparison of Conventional and Integrated Pest Management Programs in Public Schools

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ABSTRACT This study compared an integrated pest management (IPM) program with conventional, calendar-based pest control in nine North Carolina elementary schools. Both programs primarily targeted the German cockroach, *Blattella germanica* (L.). The IPM program relied heavily on monitoring and baiting, whereas the conventional approach used baseboard and crack-and-crevice sprays of insecticides. Within the constraints of an existing pest management contract, we quantified service duration, materials used, cost, levels of cockroach infestation, and the pesticide residues generated by the two service types. IPM services were significantly more time-consuming than conventional services, resulting in a significantly higher cost associated with labor. Nevertheless, the two types of treatments incurred similar total costs, and the efficacy of both treatments was also similar. Most importantly, pest monitoring, a central element of the IPM program, revealed few cockroaches and indicated that most of the conventional treatments were unnecessary. Environmental residues of the organophosphate pesticides acephate, chlorpyrifos, and propetamphos were significantly higher in swab samples taken in the conventionally treated schools. This study demonstrates that an IPM program is an appropriate and preferable alternative to conventional methods of pest control in the school environment.

KEY WORDS school IPM, IPM, German cockroach, *Blattella germanica*

EXPOSURE OF CHILDREN TO PESTICIDES has been a major public concern for the past several decades, first brought to public attention by the National Research Council report *Pesticides in the Diets of Infants and Children* (National Research Council 1993) and further motivated by the observations that "pound for pound of body weight, children breathe more, eat more, and have more rapid metabolisms than adults, and they also play on the floor and lawn where pesticides are commonly applied" (USGAO 1999). Children therefore are at greater risk of pesticide exposure, and the health impact may be more profound than for the rest of the population. Recent interest has focused specifically on pesticide use in schools, in part in response to reports of the American Association of Poison Control Centers that there were 2,300 complaints of pesticide-related exposures in schools between 1993 and 1996 (USGAO 1999).

The school environment creates a unique problem for insect pest suppression because schools are expected to be pest-free, while still restricting occupants' exposure to pesticides. In an effort to understand who is conducting pest control in schools, the North Carolina Cooperative Extension Service conducted a survey of 120 public school systems in North Carolina (Anonymous 1999). The survey concluded that 1) fewer than one-half of the schools used any integrated pest management (IPM) techniques to control pests; 2) 15% of the schools used school employees who were unlicensed in pest control; 3) cost was the most important factor in choosing a pest control company for 19% of the schools; 4) only 51% of the schools kept any records of pesticide applications; and 5) baseboard applications of residual broad-spectrum pesticides was reported in 70% of the schools. These general findings are probably not unique to North Carolina.

In the school environment, IPM can serve to prevent pest problems while reducing the risk of pesticide exposure to children. Yet, as of 2005, fewer than one-half of the states in the United States have laws requiring the use of IPM techniques in their schools, and the School Environmental Protection Act (U.S. House of Representatives 2005), which was originally introduced in 1999 to require the use of IPM methods in all public schools, has yet to be adopted as federal legislation. Although most experts agree that IPM programs will benefit schools and children, there are also enduring concerns over such legislation (USGAO 1999), mainly related to the cost of IPM programs, which is thought to be higher than conventional pest control. Also, there is apprehension that national mandates would be too broad to address the specific pest

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control needs in different areas of the country. And finally, once IPM is mandated, there is uncertainty about implementation and enforcement of these laws to ensure that schools are in compliance.

A review of our current understanding of pest management in schools plainly reveals that scarcely any data exist on the types of pesticides used in schools, where they are applied, program costs, or the efficacy of such services. Therefore, deliberations for or against adoption of IPM approaches are largely based on conjecture and subjective judgment. We undertook an analysis of two distinct pest management programs in public schools in an effort to compare the costs and benefits of these approaches.

Materials and Methods

Schools. The study was conducted in Nash County, North Carolina. Public elementary schools were included in the study based on their pest populations, similarity of school age and design, and the cooperation of the pest control company, which was contracted to service all nine schools and associated administrative buildings. According to the contract agreement, the schools were to be serviced monthly, but the type of service and materials were not specified. The areas specified to be serviced each month were vending machine areas and lounges, cafeteria serving, preparation, dish washing, and dining areas, all restrooms, and custodial closets. Classrooms were treated only when a pest problem was reported. The pest management professional (PMP) made all decisions about the types and amounts of pesticides applied and areas treated.

Conventional and IPM Services. The study was conducted during a 12-mo period, from March to February. For the first 5 mo, all nine schools were under the conventional pest control service, and during this time baseline data were collected to describe this program. The conventional services were in place before this study began and served to represent a typical pest control service in North Carolina schools. Those services were simply observed, and no attempt was made to change the services in any way. In August, five of the schools were switched to an IPM program and monitored for 6 mo until February. The remaining four schools continued to be serviced with the conventional methods.

The conventional service consisted of monthly applications of residual pesticides to baseboards in key areas. Applications were made with a 3.785-liter pressurized spray tank with a pin-stream nozzle (Prime Line, B&G Equipment Co., Plumsteadville, PA). Treated areas included all bathrooms, cafeteria kitchen (including the serving, preparation, dish washing, and storage areas), cafeteria dining room, teachers' lounge, custodial closets, principal's office, and the secretarial office. Other areas were treated as requested by the school staff regardless of pest presence. Although insecticide baits were occasionally used by the PMP, they were often used after an area had been treated with a liquid insecticide. The following products were used in the conventional services: Orthene Crack and Crevice Pressurized Residual (Whitmire Micro-Gen, St. Louis, MO), Maxforce Roach Bait Stations and Maxforce FC Roach Killer Bait Gel (Maxforce Insect Control Systems, Oakland, CA), Invader Residual Insecticide with Baygon (Waterbury Companies, Inc., Independence, LA), and Gentrol IGR Concentrate and Catalyst Emulsified in Water Insecticide (Wellmark International, Bensenville, IL). The conventional service did not include any regular inspections for pest problems or follow-up inspections of problem areas.

In July, the PMP was trained in IPM principles, based upon guidelines established by the North Carolina State University School IPM Committee. The IPM program consisted of only the most fundamental components of IPM because it had to be implemented within the general time and financial constraints of the existing pest control contract. Generally, each IPM service consisted of visual inspections of all key areas described for the conventional service. Insect glue traps (Trapper Monitor & Insect Trap #TM2601, Bell Laboratories, Inc., Madison, WI) or rodent glue boards (Catchmaster # 72MB-PB, Atlantic Paste and Glue Co. Inc., Brooklyn, NY) were placed in areas with the greatest pest potential. Any pest sightings reported by the staff were followed-up with an intensive inspection. If no pests were found, then traps were deployed in the area and checked the following service (month). Pest problems were treated only on an as-needed basis with the least hazardous (not necessarily least toxic) formulations that would provide quick and lasting control. An action threshold of one live cockroach per room was used due to the length of time (1 mo) between successive visits, and the high reproductive potential of the German cockroach. The following products were used in the IPM services: Drax Ant Kill Gel and Drax Ant Kil-PF (Waterbury Companies, Inc.); Outsmart Sweet Ant Bait Gel (BioSmart Ideas, Inc., Royal Palm Beach, FL); Maxforce Ant Killer Bait Stations, Maxforce Fine Granule Insect Bait, Maxforce Roach Bait Stations, and Maxforce FC Roach Killer Bait Gel (Maxforce Insect Control Systems); and Advance Granular Ant Bait and Inspector Pressurized Contact Insecticide (Whitmire Micro-Gen).

Analyses of Pest Control Services. Each school was serviced monthly, and data were collected from 46 conventional services over 9 mo and 26 IPM services over 5 mo. Each service was timed starting when the PMP entered the school and ending when the PMP exited the school. Travel time to the schools was not recorded. The area of regularly serviced rooms in each treatment was calculated from blueprints to ensure that any difference in service durations was not due to differences in the size of the schools. There was no significant difference between the areas serviced in the conventional and IPM schools ($t = 0.33$; df = 7; $P = 0.75$).

The materials used during each service were recorded. The volume of pesticide applied with the pressurized sprayer was estimated by monitoring the level in the tank before and after each service. The amount of material applied during aerosol applications was extrapolated from the duration of each application and the amount dispensed into a graduated cylinder during a timed application. The amount of bait in the translucent container was measured before and after each service. Bait stations, monitors, and glue boards were counted as used.

The amount of active ingredient applied was calculated based upon the percentage of active ingredient as stated in each product label. For liquid products, volumetric units were converted into mass according to their specific gravity as listed on the material safety data sheet (MSDS). The mammalian LD_{50} values also were obtained from the MSDS when available or calculated from the LD_{50} values of the active ingredient.

Cost of each service was determined by combining the cost of labor and materials. An hourly labor rate of $8.75 was calculated from the annual salary of the PMP and a 40-h workweek. The labor cost of each visit was calculated from this hourly rate and the duration of the service. The cost of materials was determined from product prices obtained from a local pest control vendor. Thus, these cost estimates are for performance of the respective pest control services and do not represent the actual cost to the school.

Several intensive inspections for cockroaches did not yield any useable data because of the generally low infestations in these schools. Also, reports of pest problems from faculty were determined to be insufficiently reliable (e.g., misidentification of pests) to be used in determining pest levels. Therefore, the number of cockroaches present was determined from trap catches. Traps were placed in the same areas that were regularly treated or inspected in all of the schools. An average of 13 ± 1.5 traps was always present in each school to monitor cockroach levels.

Sampling Insecticide Residues. Unfortunately, before we collected pesticide residue samples from the IPM-serviced schools at the conclusion of the study, the pest control contract was awarded to a different company, which promptly treated the five schools with baseboard applications of residual insecticides. Therefore, five different schools were recruited in Wake County, North Carolina, for this part of the study. These schools were serviced by trained inhouse PMPs who implemented IPM approaches similar to ours.

Sample collection methods were modified from Wright et al. (1984). Samples were collected in each school from the bathroom, main office, dining room, cafeteria, and teachers' lounge. Other areas such as hallways and classrooms were randomly sampled as well. Samples were taken from baseboards where insecticides were generally applied, and from walls ≈90 cm above the baseboard, representing a nontarget area that a child may contact. A sterile cotton ball was soaked in isopropyl alcohol, excess alcohol was removed by squeezing with sterile forceps, and the cotton ball was then drawn repeatedly across a 100-cm^2 surface with a latex-gloved hand. The swabbing procedure was repeated with a second cotton ball, and both cotton balls were stored in 20-ml isopropyl alcohol in a glass vial with a Teflon-lined cap. Control samples were prepared by placing sterile cotton balls directly into collection vials. All samples were stored in the dark at −20°C.

Each sample was extracted by sonication in acetone (Branson #450, Branson Ultrasonics Corporation, Danbury, CT) for 2 min. The sample volume was reduced in a 40°C rotary evaporator to ≈5 ml, filtered through a 0.45-μm syringe filter, reduced to 1 ml under a stream of N_2, transferred into 2-ml autosampler vials, and stored in the dark at 7°C until analyzed.

Sample analysis was performed on a gas chromatograph (Star 3400X, Varian Inc., Palo Alto, CA) equipped with a nitrogen-phosphorous TSD detector. A DB-35 column (30 m by 0.53 mm ID by 1-μm film thickness; Agilent Technologies, Palo Alto, CA) was temperature programmed from 170°C (2 min) to 200°C at 2°C/min (hold 2 min) and then to 280°C at 25°C/min (hold for 2 min). Helium was the carrier gas at a flow rate of 6.05 ml/min and the makeup rate was 24.93 ml/min. The inlet (splitless mode) and detector temperatures were set at 175 and 300°C, respectively. Gasses to the detector were helium and air at 4.0 and 169.1 ml/min, respectively. Data were quantified using 5 μg/ml external standards autoinjected between every five or six samples during a run.

The identities of some peaks were confirmed by mass spectrometry. We used a Network Mass Selective Detector (model 5973, Agilent Technologies) equipped with a DB-5 column (30 m by 0.32 mm ID by 0.25-μm film thickness). Two microliter injections were made into a splitless inlet at 250°C. The oven temperature was programmed from 100°C (5 min) to 300°C (5 min) at 6°C/min. The carrier gas was helium at a constant flow of 1 ml/min.

Statistical Analyses. For direct statistical comparisons of IPM and conventional treatments, only contemporaneous services were compared. Therefore, the 26 IPM services in five schools were compared with 16 conventional services in four schools. All differences were examined in SAS with pooled *t*-tests (SAS Institute 1989). For all means, SEM was used as the measure of variation.

Results

Duration of Services. The duration of each service represented the time that the PMP took to service the school, including pesticide applications, time spent talking to school staff, completing paperwork, gaining access to locked areas, and time spent waiting for children or faculty to clear an area before applications were made. The average duration of each conventional service before the nine schools were split into two treatments was 43 ± 4.5 min ($n = 30$). Initially, each of these early services were lengthy (71 ± 13.3 min/service; $n = 30$), but their duration declined to 29 ± 2.5 min/service ($n = 30$) within 4 mo and re-

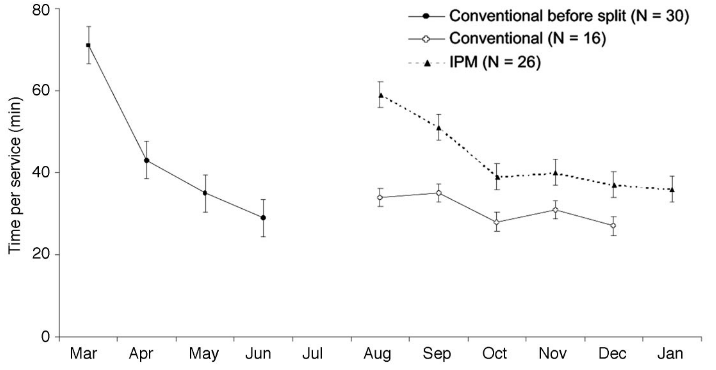

Fig. 1. Average monthly duration (mean ± SEM) of conventional and IPM services in elementary schools. Nine schools were split into two treatments (conventional and IPM) after being serviced from March to June with conventional treatments.

mained constant at ≈30 min in the four schools that remained under the conventional treatment (Fig. 1).

The average duration of each of the IPM services (45 ± 3.2 min; $n = 26$) was significantly longer than the contemporaneous conventional services ($t = 3.02$, df = 40, $P = 0.004$). Overall, conventional services were relatively invariable, whereas the IPM services varied greatly. But over time, the duration of the IPM services became shorter (Fig. 1). Under these low cockroach populations, these data suggest that in a stable program it would take only slightly longer to actively inspect and monitor a room than it takes to spray all the baseboards.

Materials Used. The amount of each active ingredient used per service in each of the two programs is listed in Table 1. Approximately 383 ± 92 ($n = 4$) linear meters of baseboard was treated during each conventional service with an average of 10.36 g of active ingredient. Propetamphos, an organophosphate insecticide, was used most often, usually in a tank mix with the insect growth regulator (IGR) hydroprene, at a rate of 9.53 ± 0.63 g active ingredient per service ($n = 16$) (Table 1).

Organophaspate pesticides were not used in the IPM services. Instead, fipronil (in a bait or gel formulation), and pyrethrins (combined with synergists in an aerosol formulation for flushing out insects during inspection) were used most often. All were used sparingly—only 11.22 mg of active ingredient was used in each IPM service—because the cockroach infestations were generally low (see below). Boric acid and hydramethylnon, both in bait formulations, also were used in the IPM services, but primarily against ants and therefore were not considered further in this study. Although not included in Table 1, traps were regularly installed in the IPM services (5.2 ± 1.1 traps/service; $n = 26$) and contributed to the overall cost of materials for the service.

Cost of Services. The cost of each service reflected the combined cost of labor and materials. Generally, labor costs figured most prominently into this calculation, and therefore the cost data (Fig. 2) closely mirror the service duration data (Fig. 1). Thus, the initial costs in both the conventional and IPM services were high, but both declined over time. The average monthly cost of the conventional services declined by 43.9% from $16.92 in March to $7.42 in June. During the following 6 mo (August to January) the average cost of this service in four schools remained relatively stable at ≈$7.50 per service. Likewise the IPM service

Table 1. Average amount of active ingredients (mean ± SEM) used in conventional and IPM services

Active ingredient (product, formulation)	Oral LD_{50} (mg/kg)[a]	Mean amt of active ingredient ± SEM (mg)		
		Conventional before split ($n = 30$)	Conventional ($n = 16$)	IPM ($n = 26$)
Abamectin (Advance-Gr)[b]	>5,000			0.01 ± 0.01
Acephate (Orthene-A)	5,190	2.46 ± 2.46		
Boric acid (Drax, Outsmart-Gel)[b]	3,160			25.0 ± 15.6
Fipronil (Maxforce-BS, Gel)	>5,000	0.34 ± 0.18		0.64 ± 0.20
Hydramethylnon (Maxforce-BS, Gr)[b]	>5,000	1.00 ± 1.00		1.35 ± 1.15
Hydroprene (Gentrol-EC)	>5,100	1,084 ± 106	832 ± 142	
Methylcarbamate (Invader-A)		96.8 ± 90.4		
n-Octyl bicycloheptene dicarboximide[c]				4.23 ± 1.19
Piperonyl butoxide[c]				4.23 ± 1.19
Pyrethrin (Inspector-A) [c]	4,730			2.12 ± 0.60
Propetamphos (Catalyst-EC)	451	10,503 ± 604	9528 ± 632	

A, aerosol; BS, bait station; EC, emulsified concentrate; G, gel; Gr, granular.
[a] LD_{50} values given are for the formulated product.
[b] These compounds were used for pests other than cockroaches.
[c] These compounds are all components of the same aerosol pesticide.

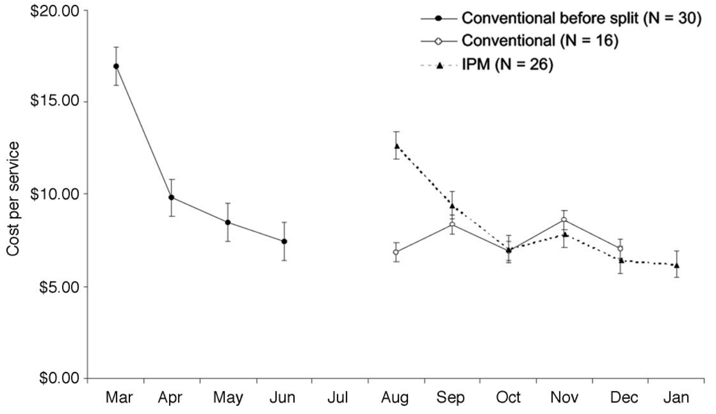

Fig. 2. Average monthly cost (mean ± SEM) of conventional and IPM services. Nine schools were split into two treatments (conventional and IPM) after being serviced from March to June with conventional treatments.

incurred a higher cost at its inception in August ($12.63), but declined by 49.1% to only $6.20 by the end of the study. At the conclusion of the study the cost of the IPM program was not significantly different from the cost of the conventional program.

The average cost of materials for each conventional service ($2.80 ± 0.29; $n = 16$) was higher than for each IPM service ($1.91 ± 0.34; $n = 26$), but the difference between the two treatments was only marginally significant ($t = 1.81$, df = 40, $P = 0.07$). However, because each IPM service was of longer duration, the average cost of labor for each ($6.66 ± 0.47; $n = 26$) was significantly higher ($t = 3.02$, df = 40, $P = 0.004$) than for each conventional service ($4.69 ± 0.34; $n = 16$). Overall, the total cost of each service (materials and labor) was approximately the same in the IPM and conventional treatments, $8.57 ± 0.73 and $7.49 ± 0.52 respectively ($t = 1.06$, df = 40, $P = 0.29$), suggesting that once established, the monthly costs of either a conventional or IPM service remain relatively constant, at least when implemented under the financial constraints of an existing contract.

Cockroach Infestation Levels. Generally, both sets of schools were not highly infested with cockroaches and live cockroaches were seen only sporadically. Only 23 of 354 traps that were deployed for 12-mo captured cockroaches. In total, only four cockroaches were trapped in the conventional schools on two occasions during 16 visits (0.25 ± 0.19 cockroaches per visit; $n = 16$), and 51 cockroaches were trapped in the IPM schools in nine unique locations during 26 visits (1.96 ± 0.78 cockroaches per visit; $n = 26$) ($t = 1.69$, df = 40, $P = 0.10$).

Pesticide Residues. In the four conventionally treated schools, 38 residue samples were swabbed from 13 areas (Table 2). As expected, more propetamphos was found in surface swabs than any other insecticide, and it was found in all areas where it was regularly applied, at an average of 38.89 ± 14.27 μg/100 cm^2 ($n = 21$). Surprisingly however, propetamphos residues also were routinely recovered from almost all nontarget areas that were sampled. On average, 1.11 ± 0.54 μg/100 cm^2 ($n = 17$) was found on walls ≈90 cm above the sites of insecticide appli-

Table 2. Pesticide residues (mean ± SEM) recovered in conventionally treated schools

Area sampled	No. samples	Mean amt (μg) of chemical per 100 cm^2 ± SEM			
		Acephate	Chlorpyrifos	Fipronil	Propetamphos
1 Office baseboard	3	3.33 ± 1.72	5.25 ± 5.08	0	96.04 ± 73.31
2 Office wall	4	0	0.08 ± 0.06	0	0.81 ± 0.72
3 Teachers' lounge baseboard	3	0	0	0	100.22 ± 50.74
4 Teachers' lounge non-target area	3	0	0.01 ± 0.01	0	0.42 ± 0.19
5 Student bathroom baseboard	4	0.28 ± 0.28	0.03 ± 0.03	0	5.22 ± 3.60
6 Student bathroom wall	4	0.003 ± 0.003	0.38 ± 0.35	0	0.19 ± 0.12
7 Cafeteria dining room baseboard	4	0	4.07 ± 2.21	0	43.64 ± 17.41
8 Cafeteria dining room wall	4	0.01 ± 0.01	0.30 ± 0.10	0	0.85 ± 0.52
9 Cafeteria kitchen baseboard	3	0	0.19 ± 0.08	0	3.07 ± 2.39
10 Cafeteria kitchen wall	2	0	0.80 ± 0.71	0	5.11 ± 4.05
11 Cafeteria food storage baseboard	1	0	0.34	0	0.89
12 Hallway baseboard	2	0	0.58 ± 0.46	0	6.34 ± 2.34
13 Classroom baseboard	1	0	0.09	0	9.64
Avg baseboards (1, 3, 5, 7, 9,11–13)	21	0.62 ± 0.33	1.63 ± 0.86	0	38.89 ± 14.27
Avg nontarget (2, 4, 6, 8, 10)	17	0.004 ± 0.003	0.27 ± 0.12	0	1.11 ± 0.54
Grand avg	38	0.29 ± 0.19	1.03 ± 0.48	0	21.99 ± 8.39

Table 3. Pesticide residues (mean ± SEM) recovered in IPM-serviced schools

Area sampled	No. samples	Mean amt (μg) of chemical per 100 cm^2 ± SEM			
		Acephate	Chlorpyrifos	Fipronil	Propetamphos
1 Office baseboard	5	0.01 ± 0.01	0.03 ± 0.02	0	0
2 Office wall	5	0	0.08 ± 0.05	0	0
3 Teachers' lounge baseboard	4	0	0.01 ± 0.01	0	0
4 Teachers' lounge non-target area	1	0	0.04	0	0
5 Student bathroom baseboard	5	0	0.04 ± 0.02	0	0
6 Student bathroom wall	5	0	0.01 ± 0.01	0	0
7 Cafeteria dining room baseboard	5	0	0.08 ± 0.04	0.03 ± 0.03	0
8 Cafeteria dining room wall	5	0	0.04 ± 0.02	0	0
9 Cafeteria kitchen baseboard	5	0	0.04 ± 0.02	0.17 ± 0.17	0
10 Cafeteria kitchen wall	5	0	0.06 ± 0.04	0	0
11 Cafeteria food storage baseboard	5	0	0.14 ± 0.11	0.01 ± 0.01	0
12 Hallway baseboard	1	0	0.01	0	0
13 Classroom baseboard	1	0	0	0	0
Avg baseboards (1, 3, 5, 7, 9,11–13)	31	0.001 ± 0.001	0.06 ± 0.02	0.03 ± 0.03	0
Avg nontarget (2, 4, 6, 8, 10)	21	0	0.05 ± 0.02	0	0
Grand avg	52	0.001 ± 0.001	0.05 ± 0.01	0.02 ± 0.02	0

cation. Paired comparisons of baseboard and wall samples ($n = 15$) indicated that 165.5 ± 50.6-fold more pesticide was recovered from the baseboard than from the respective wall ($t = 2.78$, df = 14, $P = 0.01$). Interestingly, in the cafeteria kitchen, 60.1% more propetamphos was found on the walls than on baseboards, probably because the kitchen floor was more frequently cleaned. We did not quantity hydroprene residues in these samples.

During the initial conventional services, crack-and-crevice applications of acephate, another organophosphate insecticide, were made infrequently, only 2.46 ± 2.46 mg per service ($n = 30$) (Table 1). Small amounts of acephate were recovered from only five of the 38 areas sampled and in 13.2% of the total samples (Table 2). Although we had no record of chlorpyrifos applications during any of the conventional pest control services, chlorpyrifos was recovered in 12 of the 13 areas sampled and in 71.1% of the 38 total samples. Small amounts of fipronil gel (0.34 ± 0.18 mg per service; $n = 30$) were occasionally applied in cracks and crevices for cockroach control in the conventional schools. However, no fipronil residues were recovered from any of the samples collected.

In contrast to conventionally-treated schools, little pesticide deposits were found in schools under an IPM-guided service. In total, 52 samples were taken from 13 areas in five IPM schools (Table 3). Because a new set of IPM schools was recruited for the residue study the types of pesticides applied in these schools are known only from records and not from direct observations. Propetamphos residues were never recovered, and only one sample contained a small amount (0.04 μg/100 cm^2) of acephate (Table 3), consistent with records indicating that these pesticides were not used in the IPM schools. We were surprised, however, to recover residues of chlorpyrifos from 75% of the samples in the IPM schools, with a fairly uniform distribution on baseboards and walls (Table 3). Nevertheless, the level of chlorpyrifos residues found in the IPM schools was significantly lower than chlorpyrifos residues found in the conventionally serviced schools ($t = 2.36$, df = 88, $P = 0.02$).

Discussion

This study consisted of a focal survey of PMP practices in two common pest control programs in North Carolina elementary schools. It demonstrates that in a school environment with relatively mild cockroach problems, even a basic IPM program can be implemented with essentially no negative trade-offs. The benefits of the IPM approach were clear: significantly less insecticide used with considerably lower mammalian toxicity, almost no insecticide residues were available for children to contact compared with applications of residual spray insecticides, and insecticide translocation was essentially undetectable compared with the extensive drift of residual insecticides. Although data on the comparative efficacy of the two approaches were limited, we can conclude that both methods controlled cockroaches equally. Therefore, overall, the IPM program is preferable to conventional methods of pest control for health, environmental, and economic reasons. A much more thorough IPM design, incorporating extensive pest exclusion, structural modification, and more intensive monthly services, would have undoubtedly been even more effective. However, our research was constrained by contractual arrangements between the schools and a pest control company and a more intensive IPM program would have had limited appeal to both under their respective contractual obligations.

A major impediment to the adoption of IPM practices, especially in schools, is the perception that they incur higher costs. Indeed, the start-up costs of the IPM service were higher than costs associated with an ongoing conventional program (Fig. 2). However, the conventional service also incurred higher initial costs, suggesting that the initial higher costs in both programs were related to the PMP spending more time becoming familiar with the elements of each program and becoming more comfortable being observed.

Nevertheless, there are several expected cost advantages to the IPM approach, not obvious from this study. Labor, and thus the duration of each service, is the major contributor to overall cost (also see Miller and Meek 2004). Whereas most IPM-related tasks (e.g., caulking, baiting) can be made during school hours, resulting in more flexible work hours, the conventional services (e.g., baseboard and crack-and-crevice spraying) require that all people vacate the rooms. In the conventionally serviced schools the PMP routinely waited for students to be dismissed before initiating a pesticide application. More importantly, pesticides, primarily baits, used in the IPM schools, have long residual activity and are generally placed in areas that are less likely to be exposed to routine cleaning. Therefore, in the long-term, it is expected that subsequent services would use less bait, resulting in cost savings in materials and further reducing pesticide exposure to occupants.

However, our cost estimates of the IPM services did not include time spent on training the PMP because they had received earlier training in general pest control and only a brief refresher in IPM techniques was necessary. Because school personnel in many districts are responsible for pest control services and they are not familiar with IPM, much more extensive training would be required for proficiency in IPM tactics. Some have contended that training costs should be included in estimates of the total cost of IPM programs (Rambo 1998; Washington State Department of Ecology-Hazardous Waste and Toxics Reduction Program 1999). However, as certification requirements change and IPM becomes a common element of PMP training, training costs are expected to be no different than for conventional pest control, and no cost adjustment would be necessary. The shift to IPM will obviously accelerate if schools specify in their pest control contracts that only individuals trained in IPM may conduct services.

Our results also underestimate the actual cost of implementing pest control services because this study was conducted within an existing contract with specifications for conventional pest control services under a lowest bid arrangement. We considered actual costs, without consideration of the contract costs, that is, the cost to the school. Rambo (1998) suggested that in the northeastern United States, conventional pest control services cost schools about $65 per hour, whereas IPM programs sell for about $80 per hour. Although costs in North Carolina may be significantly lower, over time the differential between the two service types should disappear because of hidden costs associated with conventional services. Liability is lessened, and therefore insurance costs should be dramatically reduced with IPM services. Likewise, equipment costs are considerably lower than in conventional services. However, a more thorough IPM program, including pest exclusion, changes in sanitation, and education of students and staff could significantly increase the cost of IPM services. In the long term, however, a more complete IPM program also should prevent pest problems, thereby reducing both the frequency of visits to each school and labor costs.

The 29% difference that we observed in duration (=cost) between conventional and IPM services would be expected to be greater with more severe infestations. IPM services in heavily infested apartments, for example, took ≈80% longer than conventional services (Miller and Meek 2004). The duration of the conventional services was relatively invariable in our analysis because this service was conducted with little regard to the pest population; the same areas were sprayed every month whether pests were present or not. Conversely, the IPM service responded to cockroaches in traps with a thorough inspection, increased monitoring, targeted baiting, and several follow-up visits, all of which took longer than attending to pest problems in the conventional manner. However, because the IPM treatment is far more efficacious than the conventional methods in heavy infestations (Miller and Meek 2004), a decline in the cost of materials and labor would be expected over time in the IPM service and not under conventional treatments.

Detection and monitoring of cockroaches can be made as real-time visual inspections or by trapping cockroaches (Schal and Hamilton 1990; Owens 1995). The monitoring efforts of this research had two distinct objectives: 1) As part of the IPM program, monitoring was used to target pest control efforts to infested sites; and 2) as part of an independent assessment of the efficacy of both programs, monitoring was used to provide rough estimates of pest populations. Both objectives were addressed with visual inspections and traps. However, the low cockroach infestations precluded a quantitative analysis of visual counts, and hence all data on efficacy were derived from traps that were deployed for 1-mo intervals. Even so, few cockroaches were trapped in the schools throughout this study (only 23 of 354 traps that were deployed for 12-mo captured cockroaches), and the trapping data suggest only spotty and unpredictable infestations. Overall, both types of services resulted in similar efficacy. In a similar study in apartments, with larger cockroach infestations, the IPM treatment was far more efficacious than the conventional methods, and in fact the conventional services were almost completely ineffective against large infestations (Miller and Meek 2004). The same would be expected in schools.

The two pest control programs differed markedly in the types, formulations, amounts, and toxicity of the insecticides they used. Consequently, they also differed significantly in the amount and spatial distribution of insecticide residues that resulted from the applications. The conventional services were based on monthly applications of emulsifiable concentrate formulations of broad-spectrum pesticides to all baseboards, whereas the IPM program used primarily baits. Consequently, the mammalian toxicity of the formulated products used in IPM services was lower (Table 1), and 99.9% less active ingredient was used in IPM services (Tables 2 and 3), consistent with similar comparisons in apartments (Miller and Meek 2004). Obviously, the less pesticide that is applied, the less chance there is for children to be exposed to it.

Furthermore, the two types of services differed dramatically in bioavailability and translocation of the insecticides. Baseboard spraying of liquid pesticides requires mixing of concentrated insecticides in an air-pressurized tank, a procedure that can, and on occasion did, leave residues of highly concentrated pesticide on the floor. Pressurized sprayers also are prone to leakage when they are not well maintained, especially from the wand and nozzle, and this has been suggested to cause significant amounts of nontarget contamination (Stout et al. 1995). Because the application was directed with a pin-stream nozzle at the baseboard, it is highly available to both cockroaches and children. Moreover, this application uses large amounts of product in water over large areas. Even careful applications can result in splash-backs and aerosol formation either directly from the nozzle or from impact with the treated substrate. Tiny droplets of pesticide are thus generated that are prone to drift to nontarget areas (Jackson and Wright 1975; Leidy et al. 1987; Wright et al. 1984, 1989). Misapplications also are more likely and were readily observed on several occasions, as pesticide was applied where it was not intended because the PMP was momentarily distracted. The results of the environmental sampling, showing pesticide residues on both target and nontarget surfaces (Table 2), confirm the drift of baseboard sprays to adjacent areas that are highly accessible to children.

Propetamphos was the primary insecticide used in the conventionally treated schools. Broadcast applications of propetamphos have been shown to create airborne residues (12–17 ng/liter) in ventilated structures hours after application (Koehler and Moye 1995). Similarly, Leidy et al. (1987) found the highest concentration of pesticide residues on the baseboards of a restaurant kitchen after spot treatments with chlorpyrifos, and Wright et al. (1989) found the highest levels of acephate residues (194.1 ± 89.7 μg/100 cm^2) immediately above a cafeteria baseboard after application with a pressurized sprayer.

Based on direct observations and written records, chlorpyrifos was never applied during any of the conventional pest control services. Yet, chlorpyrifos was recovered in 12 of the 13 areas sampled and in 71.1% of the 38 total samples. It is conceivable that the chlorpyrifos residues resulted from applications of propetamphos with the same pressurized sprayer that had previously been used to apply chlorpyrifos in another service account. The extensive distribution of chlorpyrifos in almost all samples, albeit at relatively low levels, lends support to this suggestion. However, the discrepancy between propetamphos and chlorpyrifos residues on some surfaces (e.g., the teachers' lounge baseboards) (Table 2) also implicates possible aerosol applications of chlorpyrifos by school staff.

Alternatively, chlorpyrifos residues could have drifted from other treated areas or from outside. Wright and Leidy (1980) demonstrated that airflow had the effect of increasing airborne concentrations of chlorpyrifos (0.4–0.7 $\mu g/m^3$) 4 h after crack-and-crevice applications. Moreover, because perimeter applications of pesticides create residues on indoor surfaces (Leidy and Stout 1996; Stout and Leidy 2000), it is possible that chlorpyrifos was used on the school grounds for pest control and was translocated via spray drift into the school. Last, chlorpyrifos residues remain detectable for >6 months after application (Wright et al. 1984; Leidy et al. 1987), so the residues we recovered are not necessarily the result of the widespread use of chlorpyrifos, but possibly the accumulation of residues from previous applications.

The IPM approach relied on remedial treatments of identifiable pest problems. Because visual inspections and monitoring with traps revealed few cockroaches, it was deemed that most of the monthly pesticide applications under the contractual arrangement of the conventional program were unnecessary. It was, however, critical that pest problems be found promptly, and probing chemicals provide benefits over unaided visual counts when searching for German cockroaches (Reierson and Rust 1977, Reierson et al. 1979). Pyrethrin aerosol was used in the IPM program to flush out hidden cockroaches from areas that could not be visually inspected, such as hollow pipes and deep voids. However, it was used in small amounts only after all students and staff had vacated the premises, and because it is inactive in air and it oxidizes rapidly (Windholz and Budavari 1983), it posed little hazard.

Most of the pesticides used in the IPM services were formulated as ready-to-use bait stations or baits in syringes, requiring no mixing. They were generally placed into cracks-and-crevices in difficult-to-reach places. Insecticides in bait formulations tend to exhibit much less passive drift to nontarget areas than sprays, in part because they are in a gel or solid matrix, but also because they have a much lower surface area that interacts with the atmosphere. Nevertheless, fipronil residues were recovered from three of the IPM surface samples, albeit at low levels (Table 3). On occasion, we observed gel baits flowing out of the syringe even after the application was completed. This was normally evident and easily cleaned up but could result in accumulation of residues on nontarget surfaces. Feeding cockroaches may also translocate baits in feces (Kopanic and Schal 1999) and oral secretions (Buczkowski and Schal 2001), and large cockroach populations can move significant amounts of insecticide away from its intended placement. However, because most cockroaches live and die in various voids within the structure, it is unlikely that their residues would be available to children via this route.

It is important to emphasize that the absolute values of environmental pesticide residues should not be used for formulating risk assessments. Our research did not optimize the recovery of various insecticides from different surfaces, the extraction procedure and gas chromatographic analysis, and the elapsed time between pesticide application and sample collection was variable. It has been demonstrated that total chlorpyrifos residues persist longer than transferable residues (Krieger et al. 2001). In addition human skin removes substantially less chlorpyrifos residue from surfaces than swipe samples, and <1% of the pesticide applied on a surface is actually removed as a result of direct hand contact (Lu and Fenske 1999). Nevertheless, estimates suggest that total dermal and nondietary oral doses of chlorpyrifos can be as high as 356 μg/kg/d from exposure to residues on surfaces after broadcast applications in the home (Gurunathan et al. 1998), and similar results would be expected from routine pesticide applications in schools.

In summary, an elementary IPM program, based on monitoring and reduced risk pesticides, was as effective as a conventional pest control program based on monthly applications of residual pesticides. The IPM program, however, used significantly less pesticides, the pesticides had much lower mammalian toxicity, and they resulted in significantly less environmental and off-target residues. The IPM program thus created a safer environment for children than the conventionally serviced schools. The benefits of an IPM approach far outweigh the convenience of a conventional, calendar spray-based approach and should be adopted by school systems and PMPs.

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