PENETRATION RATE OF TWO PESTICIDE CARRIERS AT A LARGE USED-TIRE STORAGE FACILITY IN CHICAGO, ILLINOIS

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ABSTRACT. During August 1987, a large and concentrated infestation of *Aedes albopictus* was discovered on the property of a tire recapper and gasket manufacturer in Chicago, IL, in a densely populated urban environment. The infestation called for special abatement procedures because of the large number of tires and the varied ways they were stacked. An effective method for delivering pesticides into the cavity of each tire is described. Corncob granules, when applied to stacked tires, effectively penetrated this larval habitat at rates of 85% in column-stacked piles, 93% in random-stacked piles and an average of 95% in shingle-stacked piles. By comparison, gypsum pellet carriers sustained penetration rates of 37% in shingle-stacked piles and 87% in random-stacked piles.

INTRODUCTION

Large numbers of used or scrap tires are the modern habitat of several pest and vector mosquitoes. Unlike some solid wastes, tires pose a unique disposal problem because they are difficult to shred and cannot be disposed of readily in landfills. The Rubber Manufacturers Association in Washington, DC, estimates that 200 million used tires are added yearly as solid waste. In recent years used tires have become an important international and domestic article of commerce (Reiter and Sprenger 1987). Between 1970 and 1985, the United States imported 15.2 million used tires (Hawley et al. 1987). For these reasons alternative methods designed to manage populations of pest and vector mosquitoes in this ever enlarging man-made habitat are needed.

Source reduction through habitat elimination or management is considered one of the preferred methods of controlling mosquito populations, and in many situations this strategy is applicable for managing mosquitoes that use artificial containers. However, there are many situations where source-reduction methods are not logistically sound or environmentally feasible. Although most used and waste tires are randomly scattered, commercial firms operate in a different manner, especially where space is limited. Commercial tire recyclers and recappers cannot destroy or alter tires nor can they bother with covering them to prevent water accumulations, because the number of tires required for their operations are excessively large. Therefore, source reduction through elimination is not always a feasible alternative. Commercial operations commonly stack tires into shingle-like or column piles. These two stacking methods create an additional problem because they limit penetration of an insecticide into interior tires by reducing the open space between tires. Unfortunately, these spaces are sufficiently great to allow mosquito colonization.

In August 1987, a localized infestation of *Aedes albopictus* (Skuse) was discovered in Chicago, IL, at a tire processing facility (Rightor et al. 1987). The infestation site, estimated to consist of over 500,000 tires, is surrounded by a densely populated urban environment. Most tires stored and used at this site were from the Chicago area, although additional used-tire casings were obtained from numerous locations in the United States, including Houston, TX, St. Louis, MO, Kansas City, MO, and Memphis, TN.

The Chicago infestation demanded special abatement procedures because of the large number of tires and the many ways in which they were stacked. Tires, despite their position, collect and hold water when stored out-of-doors. Plans to abate mosquitoes must be directed at the immature aquatic stages. The vast number of tires present precluded emptying each tire manually. The situation warranted the use of a pesticide attached to a carrier that could penetrate all tires regardless of the stacking method used. The possibility of multiple exposure of factory workers to toxicants and the proximity of urban residential properties prevented the use of standard pesticides and pesticide application procedures.

Previously, Novak et al. (1985) reported that corncob granular formulations of temephos and *Bacillus thuringiensis* var. *israelensis* (*B.t.i.*) effectively controlled *Aedes aegypti* (Linn.) larvae in tires and other containers. They concluded that the intrinsic physical properties of a granular corncob carrier allowed maximal versatility regarding formulation and dispersal with ground and aerial equipment. The purpose of our investigation was to determine and evaluate the efficacy of corncob granule and gypsum pellet dis-

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persal in tire piles having multiple tire-stacking configurations. The gypsum pellet carrier was used in comparative tests because we considered it to be an effective carrier of both *B.t.i.* and temephos.

MATERIALS AND METHODS

The study site was located on the property of a Chicago tire recapper and gasket manufacturer (Fig. 1A). A wide variety of used tires were exposed to the weather in open lots. Throughout the year a minimum of 500,000 tires was maintained by the manufacturer.

Tires were stacked in 3 different configurations that maximized use of available storage space. These configurations consisted of: 1) car and light truck tires arranged in shingled stacks with each adjacent tire overlapping its neighbor in horizontal rows (Fig. 1B); 2) heavy truck tires stacked in columns one on top of another (Fig. 1C) and 3) automobile and light truck tires thrown into random piles without regard for tire position (Fig. 1D). Shingled piles consisted of horizontal rows each composed of 24–30 tires. The horizontal rows were stacked one on top of the other ranging from 10 to 28 rows and laterally ranging from 14 to 28 rows, giving these tire piles a flat-topped pyramid-like shape.

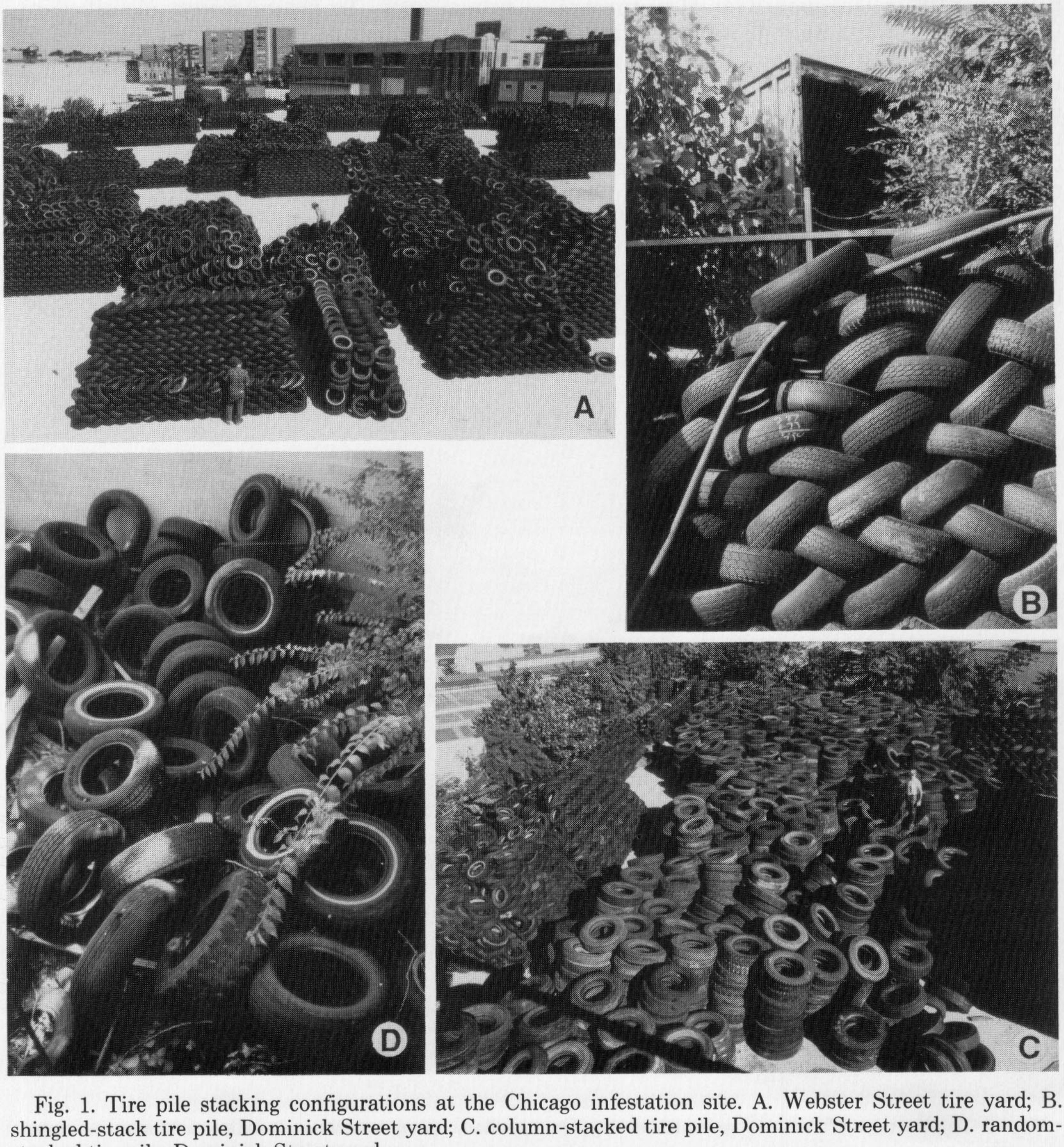

Fig. 1. Tire pile stacking configurations at the Chicago infestation site. A. Webster Street tire yard; B. shingled-stack tire pile, Dominick Street yard; C. column-stacked tire pile, Dominick Street yard; D. random-stacked tire pile, Dominick Street yard.

Large truck tires were stacked in columns 2–12 tires high, 14 columns per row and 8 columns deep. The random piles consisted of approximately 2,000–3,000 haphazardly stacked tires.

Blank corncob granules (8-mesh) were applied to shingle-, random- and column-stacked tire piles, and gypsum pellets (0.1 g/pellet) were applied to shingle-and random-stacked tire piles to determine penetration rates. Application was made from a mobile elevated platform (cherry-picker) that was approximately 1.5 m above the tire piles with an Echo DM-9 backpack applicator (Fig. 2). Above-ground treatment was augmented by ground-level applications around the perimeter of the tire piles when possible.

An application rate of 2.2 kg of granules or pellets per 300 m^3 was applied for all treatments. Granules and pellets were allowed to settle for 48 h to optimize post-treatment movement within tire piles. Shingled-, column- and random-stacked tire piles were dismantled along transects perpendicular to the long axes. Sections of tires (sectors) to be sampled along these transects were partitioned by location (upper, lower, sides) or by the amount and duration of shade. Before individual tires were moved, excess granules or pellets lying on the outside of the tires were swept away from the pile to eliminate potential contamination of tires lower in the pile. This was followed by carefully removing each tire from the sector and examining it for the presence of granules or pellets. The range of granules or pellets from 75 upper and 71 lower located tires from shingled and random piles were counted and placed into the following categories; 1–50, 51–250 and greater than 250 granules per tire.

Mosquito larvae and pupae were collected from a total of 94 tires in shingle and random piles. The entire water contents of each tire was removed using plastic 250-ml cups and passed through a sieve that retained second instar or larger mosquito larvae and pupae. Mosquito larvae were removed, killed and stored in individual 4-dram vials. To insure correct identification, pupae were held on moist cotton pads in 4-dram vials with cotton stoppers until adult eclosion. Larvae and pupae of each species were later identified and tabulated.

Tire piles representing 3 kinds of stacking arrangements were examined in 2 storage yards, the Webster Street yard and the Dominick Street yard, both located on adjacent city blocks. Six tire piles were studied to determine carrier penetration rates.

Three shingle-stacked tire piles were exam-

Fig. 2. Application of corncob granules and gypsum pellets using a mobile elevated platform, a "cherry picker."

ined. Two were located at the Webster Street yard, Shingled-Webster-Granule (S-W-Gran), and Shingled-Webster-Pellet (S-W-Pell) and one at the Dominick Street yard, Shingled-Dominick-Granule (S-D-Gran).

The S-W-Gran tire pile measured 6 × 6 × 5 m and contained approximately 8,000 automobile tires. This stack was located next to a retaining wall, with the south side shaded by small *Ailanthus altissima* Mill. trees (Tree of Heaven). A total of 430 tires were sampled from 3 sectors (front A, middle B, rear C) along a median transect. Subsamples of 4–6 tires were removed from each horizontal row within a sector and examined for granules.

The S-D-Gran pile measured 7.5 × 5.5 × 2.5 m and contained an estimated 2,500 automobile tires. This partially shaded stack was next to a fence lined with *A. altissima* trees. A total of 216 tires were sampled from 3 sectors (front A, middle B, rear C) along a median transect. Subsamples of 6 tires were removed from each horizontal row and examined for granules.

The S-W-Pell tire pile measured 10 × 5 × 3 m and contained an estimated 5,000 automobile tires. This stack was located in the middle of the Webster Street yard and was not shaded. A total of 602 tires were sampled from 3 sectors (front A, middle B, rear C). S-W-Pell sectors were partitioned into upper, external and internal samples. The upper sample was composed of the top 8 rows of tires. The external sample consisted of the outer 2 tires ending each horizontal row excluding the top 8 rows. The internal sample consisted of the remaining tires. Sector subdivisions, upper-lower, front-rear, upper-middle-bottom, upper 8 rows, external and internal samples contained similar tire numbers. All tires in each sector were scored for the presence of gypsum pellets.

Column stacks were located in the Dominick Street yard Column-Dominick-Granule (C-D-Gran). This pile measured 27 × 9 × 2 m and contained an estimated 1,500 semi-truck tires. These stacks were located in the middle of the Dominick Street yard and were not shaded. A total of 220 tires were sampled from 4 median transects (A, B, C, D). Each transect was composed of 8 individual column stacks that consisted of 2–12 truck tires. All tires within each transect were examined for corncob granules.

Two random-stacked tire piles were sampled, one at the Dominick Street yard, Random-Dominick-Granule (R-D-Gran), and a second at the Webster Street yard Random-Webster-Pellet (R-W-Pell). The R-D-Gran pile, measuring 7.0 × 4.5 × 2.5 m, was located on the north side of the yard adjacent to a fence lined with *A. altissima* trees and 3 semi-trailers that partially shaded the tire pile. A total of 162 automobile tires were sampled from 3 sectors (front A, middle B, rear C) along a median transect. Subsamples of 6 tires from all rows were scored for corncob granules.

The R-W-Pell tire pile measured 10.0 × 3.0 × 1.5 m and contained an estimated 6,000 automobile tires. This stack was partly shaded by a retaining wall and was contiguous with 2 sectors of shingled-stacked automobile tires. A total of 305 tires were sampled top to bottom from 8 sectors along a median transect. Subsamples ranging from 19 to 47 tires per sector were removed, representing the top, middle and bottom, and were scored for the presence of gypsum pellets.

Chi-square analyses were performed to identify differences in corncob granule, gypsum pellet and mosquito larval distributions within transects and sectors along transects or both. These transects or sectors along transects were further divided into front and rear, and upper, middle and bottom data assemblages to evaluate possible distributional biases that may be an artifact of application techniques. Furthermore, data assemblages were analyzed for discernible differences in larval distribution within tire stacks.

RESULTS

Penetration of corncob granules: Table 1 shows the distribution of corncob granules in the S-W-Gran tire pile. Of the 430 tires sampled, 395 tires were positive, demonstrating a 92% penetration rate. A Chi-square analysis of corncob granule penetration was done by dividing each sector into the upper 12 and lower 14 rows that contained a similar number of tires. A significant difference in the number of positive tires was found between the upper and lower sections ($P \leq 0.001$). Although the difference in distribution was significant between upper and lower sections, the percent-positive tires in all sectors ranged from 87 to 97% (Table 1). The predominate number of negative tires were found in the lower 14 rows in sectors B and C.

The distribution of corncob granules in the S-D-Gran tire pile is shown in Table 1. Of the 216 tires sampled, 210 were positive, providing a 97% penetration rate. Chi-square analysis of positive tires within sectors A–C yielded no significant difference in the distribution of granules ($0.50 < P \leq 0.70$), while comparisons between the upper and lower 6 rows of these sectors yielded a significant difference in the distribution of granules ($0.02 < P \leq 0.05$).

Table 1 shows the distribution of corncob granules at the R-D-Gran pile. Of 162 tires sampled, 150 were positive for granules, provid-

Table 1. Distribution of corncob granules by sector and upper and lower halves in the shingled-stacked tire piles at the Webster and Dominick Street lots and the random-stacked tire pile at the Dominick Street lot.

Descriptor	Sectors A	Sectors B	Sectors C	Total
S-W-Gran. (shingled/Webster St.)				
No. tires sampled				
Upper (rows 1–12)	72	72	71	215
Lower (rows 13–27)	81	78	56	215
Total	153	150	127	430
No. tires positive				
Upper	72	70	71	213
Lower	76	60	46	182
Total	148	130	117	395
Percent positive				
Upper	100	97	100	99
Lower	94	77	82	85
Total	97	87	92	92
S-D-Gran. (shingled/Dominick St.)				
No. tires sampled				
Upper (rows 1–6)	36	36	36	108
Lower (rows 7–12)	36	36	36	108
Total	72	72	72	216
No. tires positive				
Upper	36	36	36	108
Lower	35	34	33	102
Total	71	70	69	210
Percent positive				
Upper	100	100	100	100
Lower	97	94	92	94
Total	99	97	96	97
R-D-Gran. (random/Dominick St.)				
No. tires sampled				
Upper (rows 1–5)	30	30	30	90
Lower (rows 6–10)	30	30	12	72
Total	60	60	42	162
No. tires positive				
Upper	30	30	30	90
Lower	25	27	8	60
Total	55	57	38	150
Percent positive				
Upper	100	100	100	100
Lower	83	90	67	83
Total	92	95	90	93

ing a 93% penetration rate. Chi-square analysis of positive tires within sectors A–C detected no significant difference ($0.50 < P \leq 0.70$).

Table 2 includes the distribution of granules in column-stacked truck tires (C-D-Gran). Of the 220 tires sampled, 187 were positive, yielding a penetration rate of 85%. Individual Chi-square analyses of the distribution of granules within upper and lower transect halves demonstrated no significant differences ($0.20 < P \leq 0.30$ and $0.30 < P \leq 0.50$). A comparison of the front half of transects A–D yielded a significant difference ($0.01 < P \leq 0.02$), while no significant difference was detected in the rear half ($0.30 < P \leq 0.50$).

Penetration of gypsum pellets: The distribution of gypsum pellets in the S-W-Pell tire pile is depicted in Table 3. A total of 602 tires were examined, with 220 positive, producing a 37% penetration rate. Chi-square analysis of positive tires in sectors A–C showed no significant difference ($0.30 < P \leq 0.50$). The comparison of positive and negative tire distributions in the upper 8 rows (86 positive of 132 sampled), the 2 side tires ending each horizontal row (32 positive of 84 sampled) and the remaining tires (17 positive of 150 sampled) yielded similar and significant probability values ($P \leq 0.001$).

A sample of 445 tires from R-W-Pell (sectors 1–8 random-stacked, sectors 9 and 10 shingled-stacked) tire pile yielded 386 tires positive with gypsum pellets, providing a 87% penetration rate (Table 4). Chi-square analysis (2×8) of positive to negative tires in the 8 sectors showed no significant difference ($0.70 < P \leq 0.80$). Of

Table 2. Distribution of corncob granules in a column-stacked tire pile (C-D-Gran.) by transect and by location within the tire pile.

Descriptor	Transect				Total
	A	B	C	D	
Total					
No. tires sampled	68	56	46	50	220
No. tires positive	53	50	41	43	187
Percent positive	78	89	89	86	85
Upper					
No. tires sampled	31	26	22	21	100
No. tires positive	25	25	19	20	89
Percent positive	81	96	86	95	89
Lower					
No. tires sampled	37	30	24	29	120
No. tires positive	28	25	22	23	98
Percent positive	76	83	92	79	82
Front					
No. tires sampled	37	29	20	20	106
No. tires positive	28	25	20	20	93
Percent positive	76	86	100	100	88
Back					
No. tires sampled	31	27	26	30	114
No. tires positive	25	25	21	23	94
Percent positive	81	93	81	77	82

Table 3. Distribution of gypsum pellets in a shingled-stacked tire pile (S-W-Pell.) by sector.

Descriptor	Sectors			Total
	A	B	C	
No. of tires sampled	238	194	170	602
No. of tires with pellets	88	64	68	220
Percent positive	37	33	40	37

Table 4. Distribution of gypsum pellets in the random-stacked and in the contiguous horizontal shingle-stacked segment of the random-stacked tire pile (R-W-Pell).

Descriptor	Top	Middle	Bottom	Total
Random				
Total number sampled	221	130	94	445
Number positive	209	106	71	386
Percent positive	95	82	76	87
Shingle				
Total number sampled	47	47	46	140
Number positive	44	29	15	102
Percent positive	94	62	32	72

140 tires sampled in the shingled-stacked area of this pile, 102 were positive, for a 72% penetration rate (Table 4). Chi-square analysis (2 × 3) of positive and negative tire frequencies in the top, middle and bottom thirds of the shingled-stacked region yielded a significant probability value ($P \leq 0.001$). A comparison of positive and negative tires in the shingled-stacked area with the random-stacked sectors showed a significant difference ($P \leq 0.001$).

Number of granules and pellets per tire: The total number of corn cob granules and gypsum pellets per tire from 79 upper and 71 lower tires from random- and shingle-stacked tire piles are shown in Fig. 3. In upper sections of the tire piles treated with corncob granules, all 56 of the tires were positive: 32 with 51–250 granules per tire, 10 tires with 1–50 granules per tire and 14 with more than 250 granules per tire. Of the 23 tires from upper sections of tire piles treated with pellets, 5 contained no pellets and 18 had 1–50 pellets per tire. No more than 51 pellets were found per tire in any tire examined from upper sections. A total of 44 tires were examined in lower sections of tire piles treated with granules: 28 of these tires had 1–50 granules and 16

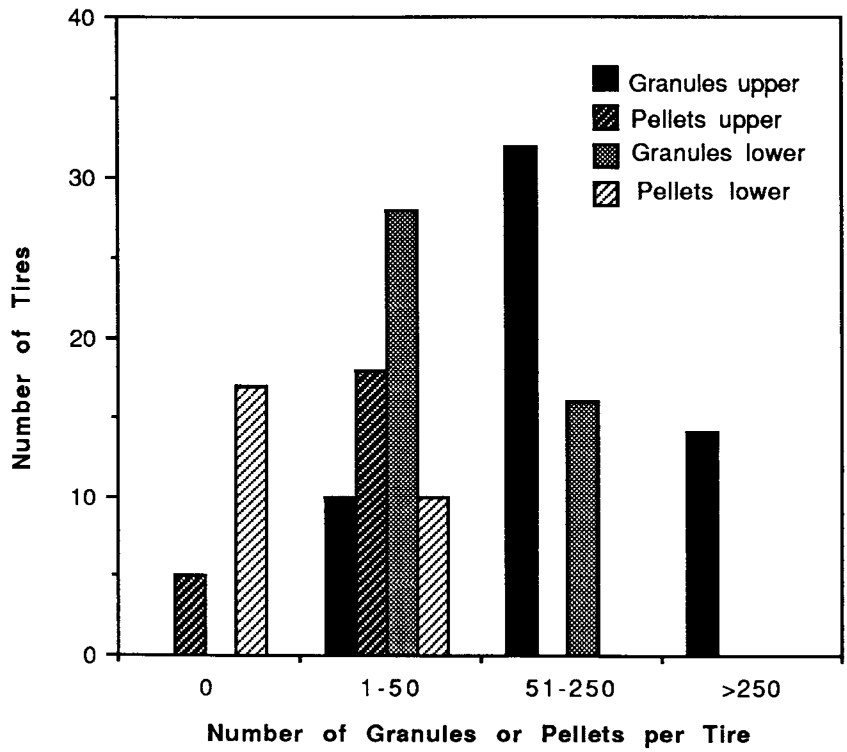

Fig. 3. The distribution of corncob granules and gypsum pellets in upper and lower sections of shingled- and random-stacked tire piles.

tires had 51–250 granules. Of the 27 tires examined that were treated with pellets from lower sections, only 10 tires had 1–50 pellets each.

Larval distribution: During this investigation, 7 species of mosquitoes representing 2 genera were collected in 94 tires from shingled- and random-stacked piles. From the genus *Aedes*, *Ae. albopictus* was collected from 78 tires, followed by *Ae. triseriatus* (Say) from 31 tires, *Ae. atropalpus* (Coquillett) from 20 tires, and *Ae. aegypti* (Linn.) from 13 tires. *Culex pipiens* (Linn.) was collected from 30 tires, followed by *Cx. restuans* Theobald from 10 tires and *Cx. salinarius* Coquillett from 2 tires.

The number of *Ae. albopictus* larvae in 78 tires from upper and lower sections of tire piles is shown in Fig. 4. The tires containing the most larvae were found in the upper sections, with 21 tires having 51–100 larvae, 29 tires with 101–250 larvae and 8 tires with more than 250. This is in contrast to tires in the lower sections, where 7 tires had 51–100 larvae, 2 tires had 102–250 and no tires had more than 250 larvae. A similar distribution of larvae was found for the other 6 species of mosquitoes.

Tires positive for mosquito larvae in shingled-, random- and column-stacked tire piles at the Dominick and Webster Street yards are shown in Table 5. The 2 shingled-stacked Webster Street piles had 25 and 56% of the tires with larvae. The Dominick Street random-stacked tire pile had 72% of the tires with larvae, the highest rate of colonization, while the column stack of tires had 19%, the lowest rate. In all of the piles examined, colonization occurred most often in the upper sections.

Tires positive for larvae and carriers: Comparing tires containing both mosquito larvae and either granules or pellets, a distinct difference was observed between the 2 types of carriers. Of the 176 mosquito-positive shingle-stacked tires treated with granules, only 5 tires lacked granules. In a similar shingle-stacked tire pile treated with pellets, 138 of 210 (66%) mosquito-positive tires examined lacked pellets. The random-stacked piles showed a similar difference between these 2 carriers. Eighty of the 82 (98%) mosquito positive tires examined contained granules, compared with 50 pellet positive tires of 102 (49%) examined. A total of 220 tires containing larvae were sampled in column-stacked tire piles of which 16 lacked granules. The penetration rate of gypsum pellets in column-stacked tire piles was not examined in this study.

DISCUSSION

This study addresses one of many problems associated with the control of mosquitoes in tire

Table 5. Distribution of mosquito larvae by sector and by upper and lower halves in the shingled-stacked tire piles at the Webster and Dominick Street lots and the random-stacked tire pile at the Dominick Street lot.

Descriptor	Number	Positive	%
S-W-Gran. (shingled/Webster St.)			
Upper (rows 1–12)	35	13	37
Lower (rows 13–27)	33	4	12
Total	68	17	25
S-D-Gran. (shingled/Dominick St.)			
Upper (rows 1–6)	54	38	70
Lower (rows 7–12)	54	22	41
Total	108	60	56
R-D-Gran. (random/Dominick St.)			
Upper (rows 1–5)	53	48	91
Lower (rows 6–10)	29	11	38
Total	82	59	72
C-D-Gran. (column/Dominick St.)			
Upper	100	28	28
Lower	120	14	12
Total	220	42	19

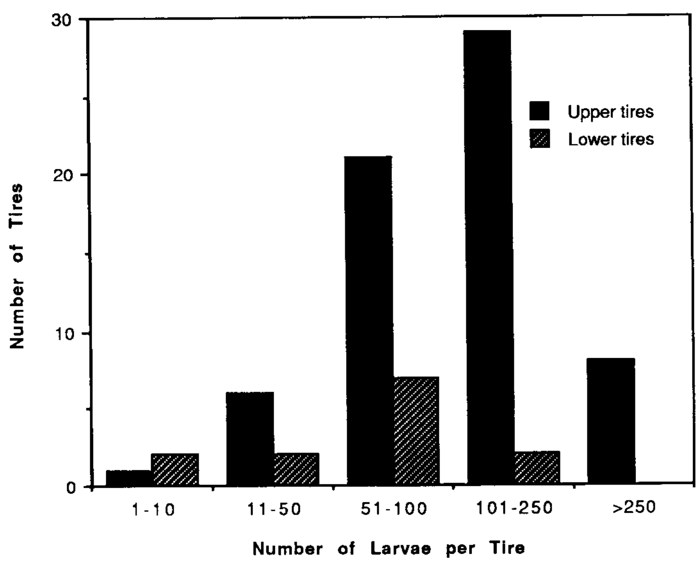

Fig. 4. Density and distribution of *Aedes albopictus* in the upper and lower sections of shingled- and random-stacked tire piles.

casings. It proposes an effective delivery of a toxicant into the cavity of each tire, whether the tire is in a random stack or placed into shingle- or column-stacked piles. Corncob granules (8-mesh) effectively penetrated the larval habitat at average rates of 85% in columns, 93% in random-, and 95% in shingled-stacked tire piles. In contrast, the gypsum pellet carrier yielded an average penetration rate of 37% in shingled stacks, and 87% in random-stacked tire piles.

These results suggest that a corncob granule carrier can more effectively penetrate large and small tire piles of various stacking configurations than can gypsum pellet carriers. Because high corncob penetration rates were confirmed in this study, variation in the distribution of mosquito larvae within tire piles is of little concern. The data further show that among the tires containing mosquito larvae in shingle and random stacks, only 7 of 258 tires lacked corncob granules whereas 190 of 310 tires lacked gypsum pellets. The penetration rates in column-stacked tires were only tested with corncob granules. Of 220 tires containing larvae, only 16 lacked granules. The 16 tires not containing larvae were located in lower sections of the columns. This could be due to the weight of the upper tires causing compression resulting in a very small opening or no opening at all in these lower tires.

The method of application was important when treating large piles of tires irrespective of stacking configuration. The application from an elevated platform (cherry-picker) so that the carrier plus insecticide can be directed laterally and down over the entire tire pile is mandatory for high penetration rates. However, the application process must include ground application around the periphery of tire piles, especially when trees or other obstacles are present.

Novak et al. (1985) reported that temephos formulated on corncob granules at a rate of 0.016 mg of active ingredient per granule resulted in over 20 days of larvicidal activity with 1 granule per tire containing *Ae. aegypti* and over 100 days when 10 granules were present. For *B.t.i.* larvicidal activity, 19 and 33 days were reported when 0.3 g and 0.5 g of granules were present in tires, respectively. The Chicago investigation demonstrates that temephos and *B.t.i.* formulated on corncob granules can penetrate a high percent of tires stacked in various configurations when applied using the technique described. High penetration rate in concert with the larvicidal activity and human safety factors associated with temephos and *B.t.i.* (Novak et al. 1985) provides an economical and logistically feasible method to manage mosquito populations in tires.

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