LABORATORY EVALUATION OF NOZZLES IN RELATION TO SPRAY PATTERNS, DRIFT, AND CONTROL OF THE GERMAN COCKROACH, *BLATTELLA GERMANICA* (LINNEAUS)

By

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INTRODUCTION

Public concern has developed in recent years over the amount of pesticides used in and around dwellings for the control of household pests. It has become important that pesticides be used in the most minimum amounts possible to obtain adequate control. In addition, it has become important to minimize drift as much as possible. This concern over the use of pesticides has led this researcher to search for more precise methods of application techniques which would eliminate some of the problems that now exist.

The primary objectives of this study were to establish which combinations of nozzles, pressures, and speeds of application would give sufficient control of the German cockroach, *Blattella germanica* (Linn.), and still produce a spray pattern with no runoff or excessive drift.

LITERATURE REVIEW

Early Research Determining the Effect of Spray Pattern, Droplet Size, and Dosage Rate in Controlling Household Pests

A number of studies have been conducted to determine what effect spray patterns, droplet size, and dosage rates have on controlling household pests. Ford (1941), using the Peet-Grady Method, found that the exposure time for houseflies could be decreased from 10 to 5 minutes if a 12 ml dosage of pyrethrum was used.

Kerr and Rafferty (1946), working with a constant pressure valve for the Peet-Grady Atomizer, found that the factor determining the size and space distribution of droplets is the pressure of the compressed air operating the atomizer.

Glasgow (1947) in comparing droplet sizes found that the smaller droplets would cover a greater total surface area than larger droplets. The effectiveness also increases further with increased convexity of the exposed surface. The surface of the droplets rapidly becomes more convex as the diameter becomes smaller.

Lindquist et al. (1945) was able to show that effective control of houseflies and mosquitoes in the home could be obtained by reducing the volume of insecticide applied. This was accomplished by increasing the concentration of the solute in the solvent. This would result in less material being used.

Yeoman and Rogers (1953) studied the factors influencing the deposit of spray droplets. They found that the distance between the nozzle and the surface being treated should not exceed that which will permit 75% of the material to be deposited on the target area. This distance should be determined for each type of nozzle when spraying a vertical or an overhead surface. They discovered that particles 50 microns or less in diameter had a tendency to drift. They concluded that more surface area will be treated when the diameter of the spray particles is greater than 50 microns.

Haller (1954) catagorized particle size in relation to type of treatment. If it is desirable to wet a wall surface in order to leave an insecticidal deposit, a coarse spray should be applied. If the particles are to be suspended in the air, an aerosol or a fog should be used.

Development of Equipment to Produce Particles of Uniform Size

The importance of producing particles of uniform size has become the primary factor in eliminating drift and producing a desirable spray pattern. Dimmock (1950) designed a vibrating hollow reed which could generate streams of droplets. All the droplets in one stream of the nozzle were of uniform size and followed the same trajectory, but each nozzle stream differed in particle size and trajectory. Primary and subsidiary droplets were formed and ranged from 10 to 300 microns. Wolf (1961) modified the vibrating reed to prevent capillary obstruction from particulates in suspension and to produce constant drop sizes. He found that by extending the length of the reed assembly droplets can be produced in remote areas.

Rayner and Hurtig (1954) produced a vibrating blade tip that could produce drops of uniform size in the range of 70 to 400 microns. This apparatus allowed the investigators to determine the effect of insecticides that are topically applied to insects. In further work with the vibrating blade, Rayner and Haliburton (1955) developed a rotary device to produce uniform drops of liquid in the diameter range of 50 to 700 microns.

In other work concerning drop size, Turner and Moulton (1953) studied droplet size distributions produced by various types of nozzles used in industrial applications.

Ennis and James (1950) studied the behavior of different droplet sizes of pesticides on vegetation, and Potts (1946) studied the factors affecting droplet size when application is made by airplane.

Development of Spray Nozzles and Equipment

Different types of spray nozzles and application equipment have been developed to distribute insecticides. Jet stream, fan, cone, full cone, and pneumatically atomized sprays were studied by Pelej (1956). He studied the nozzles and the spray patterns they produced to determine which spray nozzle would provide the most desirable spray patterns for different areas of use. He found the fan spray can be used for most situations and the jet stream for inaccessible areas. The hollow cone spray is recommended when fine particle size is desired, and the full cone spray should be used where a coarser droplet is needed.

Potter (1941) worked with atomizing nozzles that produced jet streams. He discovered that a much heavier deposit is found in the center with the deposit falling off rapidly to the outside of the sprayed area when the spray is applied directly to the surface. In addition, Potter found that an increased volume rate of air flow produced by raising the air pressure caused greater turbulence under given conditions. Hewlett (1946) improved the atomizing nozzle used by Potter

(1941) by centering the cones accurately and using a new screw device to control the vertical position of the inner cone. Roth (1965) designed a method of atomization that would produce a spray containing a narrow size range of particles of a predictable size.

Aerosols are another type of application method used for controlling household pests. Schroeder and Lindquist (1946) and Nelson et al. (1949) studied the effectiveness of aerosol dispensors.

In studying field applications, Paterson (1959) worked with hydraulic sprayers, aerosol generators and granular applications. He found that the pressure of application was very important in delivering a uniform spray. Other studies concerning drift and droplet size under field conditions were reported by Coushee (1959).

Danger of Pesticide Use in Households

With the amount of pesticides used each year in the household increasing, studies have been conducted to determine their danger. Lykken (1967) and Keil et al. (1969) studied the danger of pesticide usage in the home. These studies indicated that insecticide applications by the occupant and safety practices followed were inadequate in low income housing.

METHODS AND MATERIALS

Three fan type nozzles commonly used by pest control operators and a jet stream nozzle developed by the Oklahoma State Agricultural Engineering Department were selected for laboratory tests. These nozzles were used to determine what pressure and operator's speed would give a desirable spray pattern, produce the least amount of drift, and give adequate control of the German cockroach.

Spraying systems 50015, 800067, Multi-Teejet® fan nozzles, and 8002, Unijet® fan nozzle, were used in the test. The jet stream nozzle consisted of four 0.2 mm orifices arranged in a vertical line which produced a fan type pattern. The 0.2 mm orifice produced a droplet of approximately 400 microns.

Application pressures of 5, 10, 20 and 40 psi were tested with the operator traveling at speeds of 1.67 FPS, 2.5 FPS, and 5 FPS for each nozzle. The operator's speed was measured in feet per second (FPS). This speed was obtained by the operator using a stop watch to measure the time it took to walk 10 ft.

Modification of Application Equipment

In order to maintain and regulate the desired application pressure a one gallon stainless steel B & G sprayer, model number 104-S, was modified. The modifications (Fig. 1) consisted of replacing the pump assembly, which is designed to increase the tank pressure, with an air regulator, air gauge, outside air inlet, and petcock. The pump cylinder

Fig. 1. Modification of application equipment.

was also modified by cutting it in half and using only the upper portion which is attached to the brass cap. A 250 psi air tank was used as the air source. These modifications allowed the pressure in the spray tank to be increased or lowered. In addition, it kept the pressure constant while the spraying system was in operation.

Spraying Technique

To prevent the spray pattern from being altered, a nozzle jig stand was constructed to serve as a guide during each application (Fig. 2). This kept the angle and distance to the target area constant during each application. The guide portion of the stand was planed at a 45^{o} angle and placed 1 foot from the target area.

Spray Patterns and Drift Studies Using 3 Types of Nozzles at 4 Pressures and 3 Operator Speeds

Nozzles 50015, 800067, and 8002 were used in this test. Pressures of 5, 10, 20 and 40 psi were used with each nozzle, in conjunction with speeds of 1.67 FPS, 2.5 FPS and 5 FPS to establish which nozzle, pressure and operator's speed would given an ideal spray pattern with the least amount of drift. Spray patterns were observed by placing 4 gr of DF-545 water-soluble fluorescent dye, manufactured by Ultra-Violet Products Inc., in 1 gallon of water. The spray patterns were photographed by placing a Wratten Kodak 2B filter over the camera lens. The nozzle, pressure and operator's speed were selected at random and applied to a 4 X 22-inch poster card (Fig. 2 and 3). After each application, the poster cards were observed with a long wave black light lamp to discern the different spray patterns. During each treatment a set of nigrosin coated glass slides were placed throughout the treated area to record

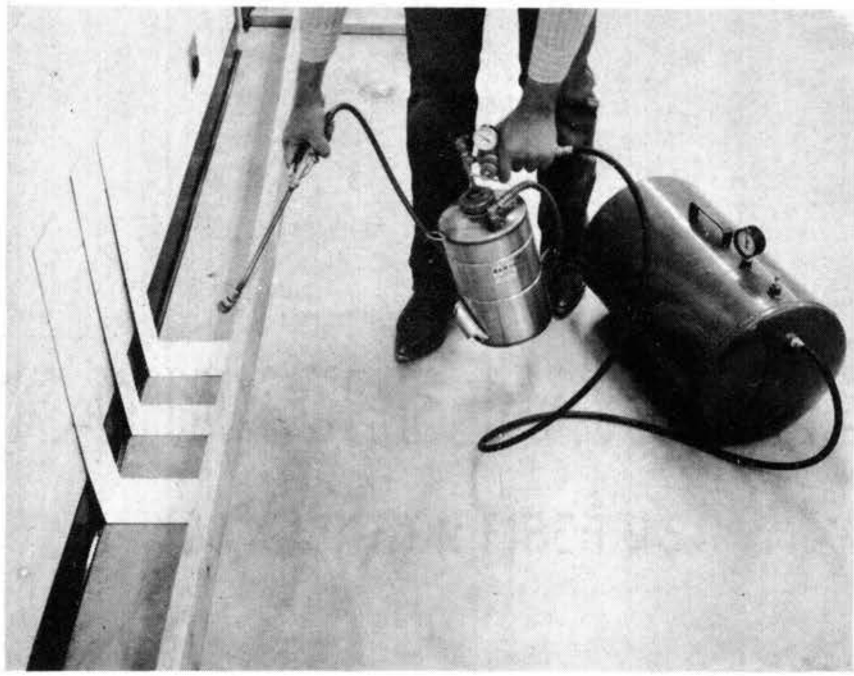

Fig. 2. Spraying technique employed to prevent distance and angle of application from being altered.

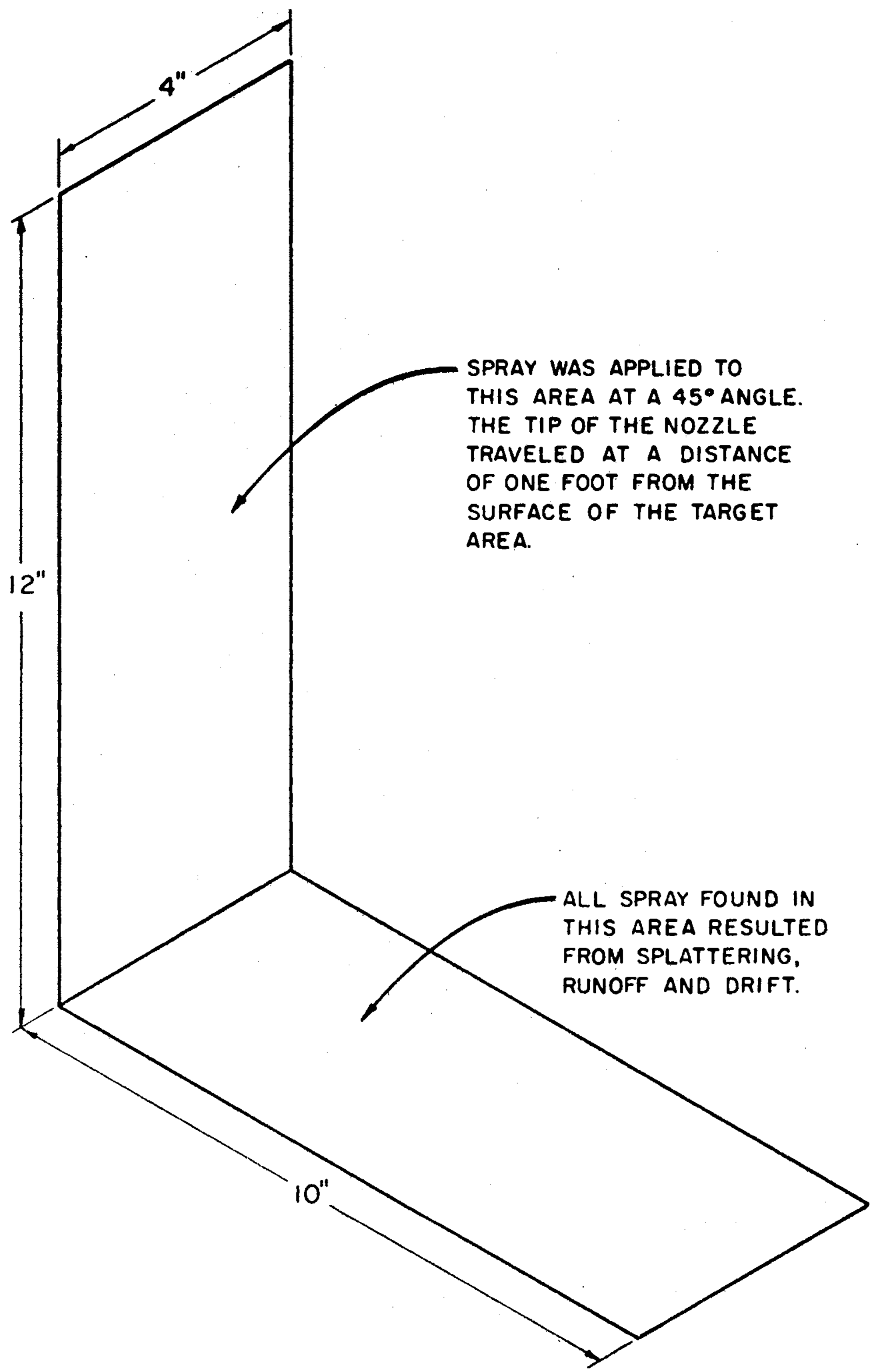

Fig. 3. An illustration of target area used in spray pattern, drift and runoff studies.

the amount of drift. After each treatment the slides were collected and observed under the black lamp. Drift accumulation was rated from light, in which 0 to 5 particles per slide were recorded, moderate, 5 particles to total coverage, and excessive, in which the slide was completely covered. Runoff was based on visual observation of the sprayed surface and was rated light, moderate or excessive.

German Cockroach Mortality and Residual Tests Over a 21 Day Period Using 3 Types of Nozzles at 4 Pressures and 1 Operator Speed

This test was conducted in a split plot design using 5 replicates. A different nozzle was used for each replicate. Analysis of variance tables containing mean squares and significant levels of variables are in the appendix.

Nozzles 800067, 50015 and the 0.2 mm nozzle were selected because of previous test results. The operator's speed of 2.5 FPS and pressures of 5, 10, 20 and 40 psi were used in this test. Glass petri dishes, 15 X 150 mm, were treated with a 1% diazinon-water emulsion. The petri dishes were treated only once, but cockroaches were subjected to the treated dishes at 7, 14 and 21 day intervals to determine the residual effectiveness of each treatment. To keep the cockroaches from escaping, a plastic ring 4-inches high was inserted inside each dish. Fifteen adult cockroaches were placed on each petri dish for 27 minutes and then transferred to 1-gallon containers. The containers were then placed at random on shelves to await further testing. The number of dead cockroaches in each container was recorded after 24 hours. This procedure is similar to the one described by Ebeling et al. (1967).

Drift Accumulation on the Operator

To demonstrate the possible drift accumulation on the operator, 1000 sq ft of vertical wall space was treated with water containing type 2267-yellow FP Traverite dye. The room treated was 7 X 24 X 8.5 feet and contained one air conditioner vent near the ceiling. From the floor surface to a height of 6 ft was the wall area treated. Nozzle 800067 at 40 psi with the operator traveling at a speed of 2.5 FPS was selected for this test. After treating the surface, the operator was photographed under ultra-violet light to show accumulation and distribution of fluorescent particles.

RESULTS AND DISCUSSION

Spray Patterns and Drift Studies Using 3 Types of Nozzles at 4 Pressures and 3 Operator Speeds

A dissimilarity between each nozzle at the same pressure as well as a variation between different pressures using the same nozzle occurs when the nozzles, pressures and speeds of operation are compared.

Nozzle 800067 produced less runoff and drift in comparison to nozzles 8002 and 50015 at all speeds and pressures tested. At the operator's speed of 5 FPS (Fig. 4), light drift was recorded at 20 and 40 psi, with very light runoff resulting at 40 psi. This speed of application is too fast for the average operator and would only be practical in spraying a straight, flat surface. At the operator's speed of 2.5 FPS (Fig. 5), light drift was recorded at 20 and 40 psi. The runoff was light at 40 psi. This operator's speed gave desirable spray patterns for all pressures tested. If the operator could maintain this speed, he could obtain a very desirable spray pattern on the target area with little drift or runoff. The operator's speed of 1.67 FPS (Fig. 6) was the least desirable spray pattern for this nozzle with light drift being recorded at 20 and 40 psi. Runoff was moderate at 20 psi and excessive at 40 psi. The performance for nozzle 800067 at each speed and pressure is given in Table 1. As the application pressure is increased and the operator's speed is decreased, the amount of insecticide applied to a surface increased. When comparing 5 psi to 40 psi at each operator's speed, the amount of insecticide applied

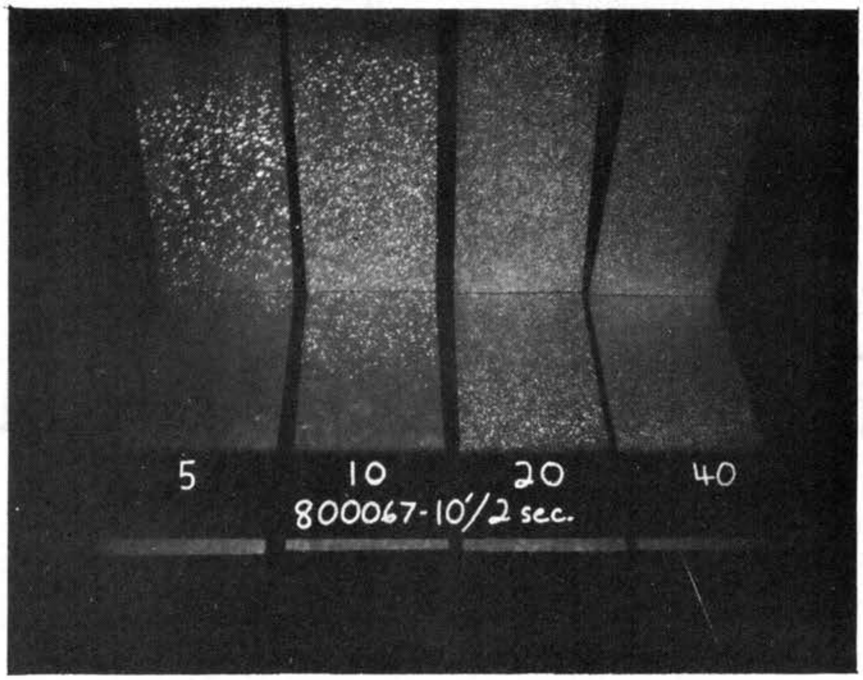

Fig. 4. Spray patterns for nozzle 800067 at 5 FPS (10 ft/2 sec) using 5, 10, 20 and 40 psi.

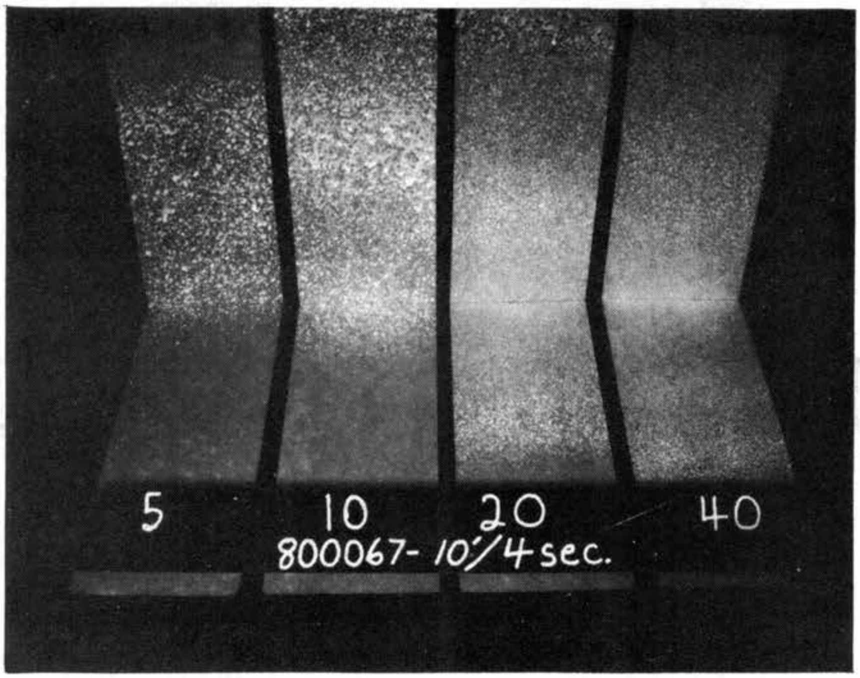

Fig. 5. Spray patterns for nozzle 800067 at 2.5 FPS (10 ft/4 sec) using 5, 10, 20 and 40 psi.

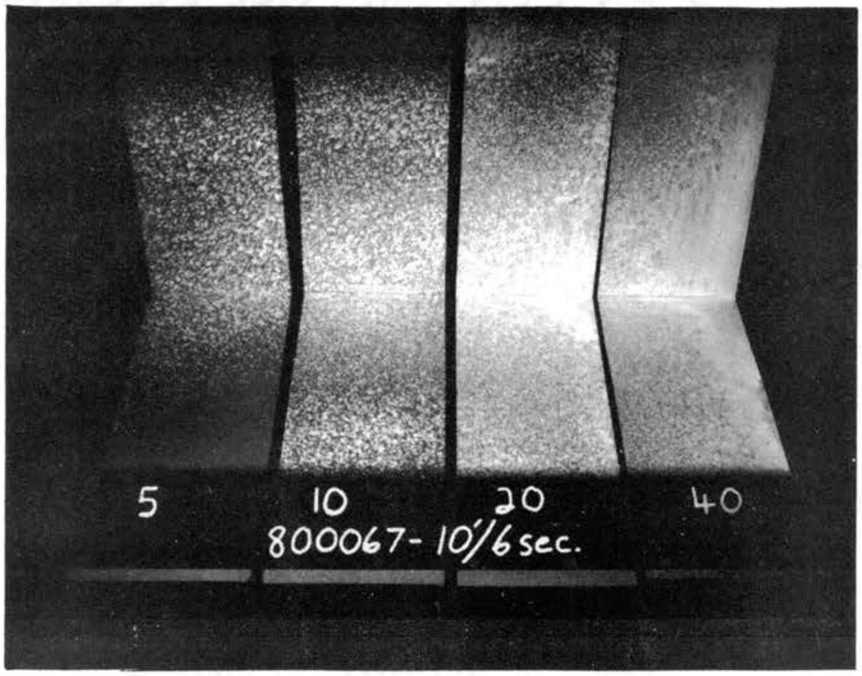

Fig. 6. Spray patterns for nozzle 800067 at 1.67 FPS (10 ft/6 sec) using 5, 10, 20 and 40 psi.

nearly doubles in each instance, with the amount of runoff and drift increasing. After observing Fig. 4, 5, and 6, it can easily be seen how an excessive amount of insecticide could be applied by altering pressure and operator's speed.

Nozzle 8002 gave the least desirable results in respect to spray pattern, runoff and drift (Table 2). At 5 FPS (Fig. 7) drift was recorded at 10, 20 and 40 psi, but no runoff was recorded. This is the only operator's speed for this nozzle that didn't produce runoff. At 2.5 FPS (Fig. 8), light drift was recorded at 10 psi, moderate drift at 20 psi, and excessive drift at 40 psi. Light runoff was produced at 5 and 10 psi, with moderate runoff at 20 psi. Excessive runoff resulted at 40 psi. The operator's speed of 1.67 FPS (Fig. 9) produced the most undesirable spray pattern for this nozzle. Moderate drift was present at 10 psi with excessive drift recorded at 20 and 40 psi. Runoff was excessive at all pressures. The amount of solution applied by this nozzle (Table 2) more than doubles from 5 psi to 40 psi and triples from 40 psi at 1.67 FPS to 40 psi at 5 FPS.

Nozzle 50015 produced a desirable spray pattern at 5 FPS and 2.5 FPS, but it caused excessive runoff at 1.67 FPS. At the operator's speed of 5 FPS (Fig. 10), light drift was noted at 20 psi with moderate drift resulting at 40 psi. Runoff was absent at all application pressures. It is felt that this speed of application is too fast for practical application. The operator's speed of 2.5 FPS (Fig. 11) caused light drift at 20 psi with moderate drift resulting at 40 psi. Light runoff was noted at 20 and 40 psi. The operator's speed of 2.5 FPS is the most desirable for this nozzle. The operator's speed of 1.67 FPS (Fig. 12) produced light drift at 20 psi with moderate drift

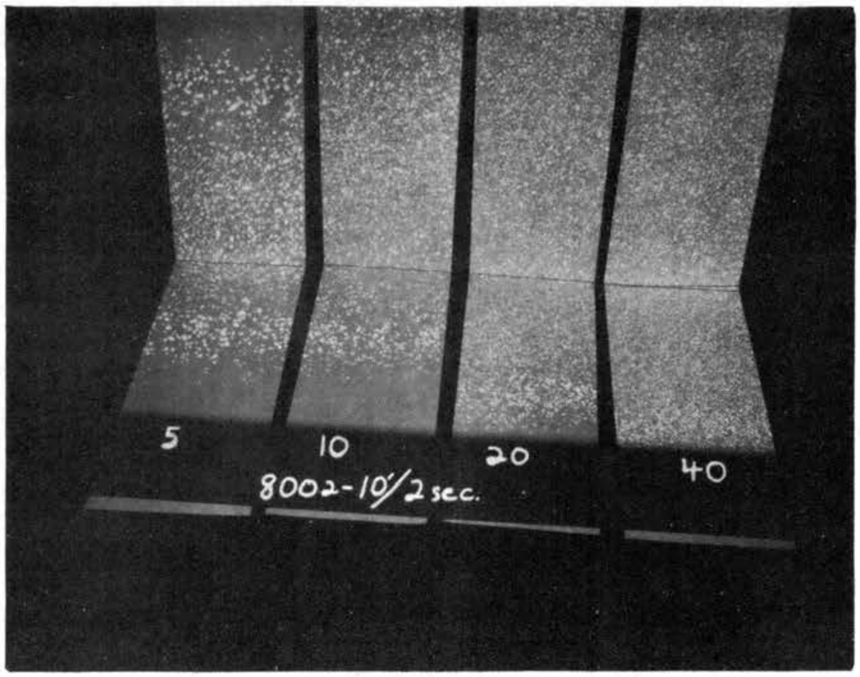

Fig. 7. Spray patterns for nozzle 8002 at 5 FPS (10 ft/2 sec) using 5, 10, 20 and 40 psi.

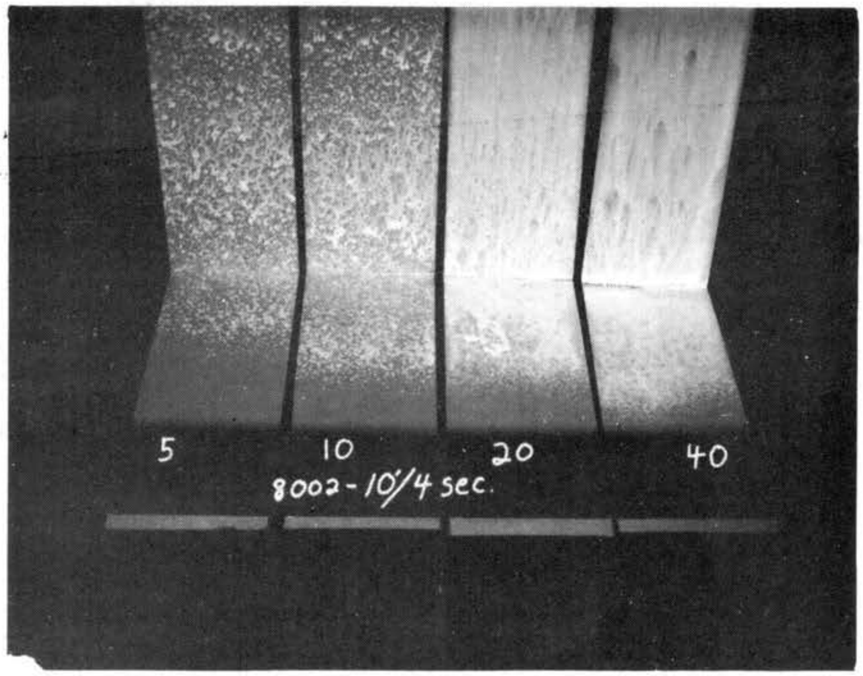

Fig. 8. Spray patterns for nozzle 8002 at 2.5 FPS (10 ft/4 sec) using 5, 10, 20 and 40 psi.

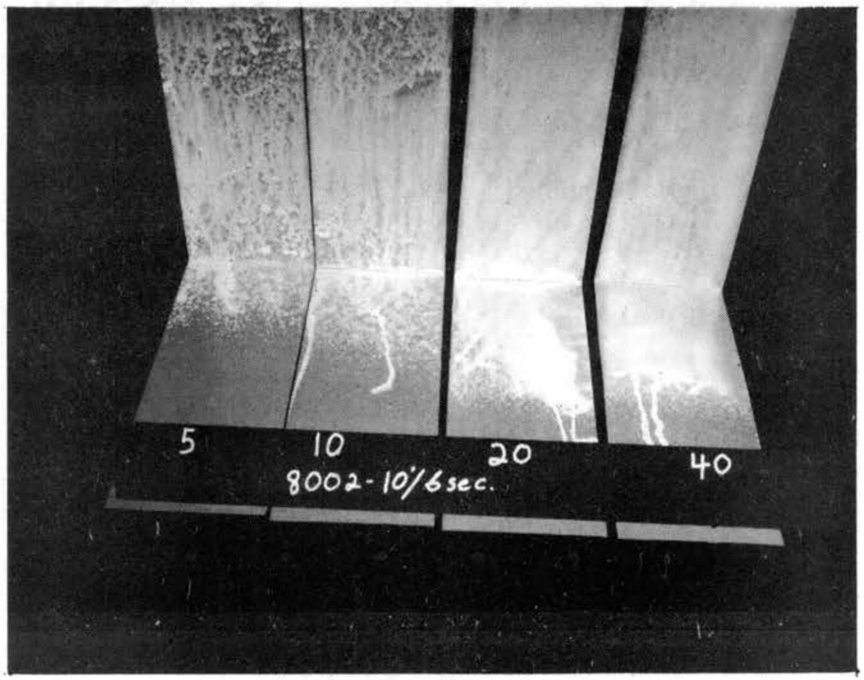

Fig. 9. Spray patterns for nozzle 8002 at 1.67 FPS (10 ft/6 sec) using 5, 10, 20 and 40 psi.

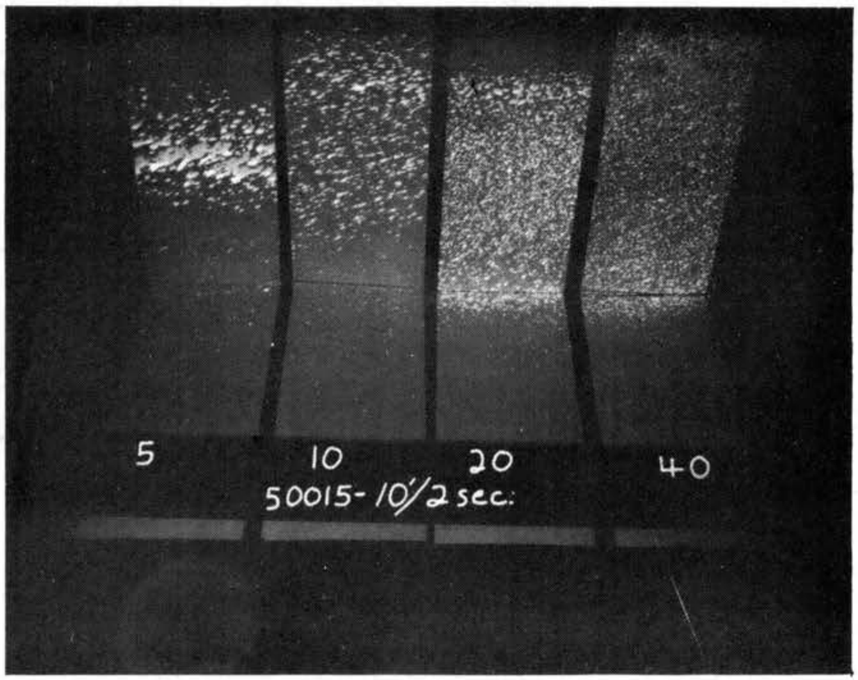

Fig. 10. Spray patterns for nozzle 50015 at 5 FPS (10 ft/2 sec) using 5, 10, 20 and 40 psi.

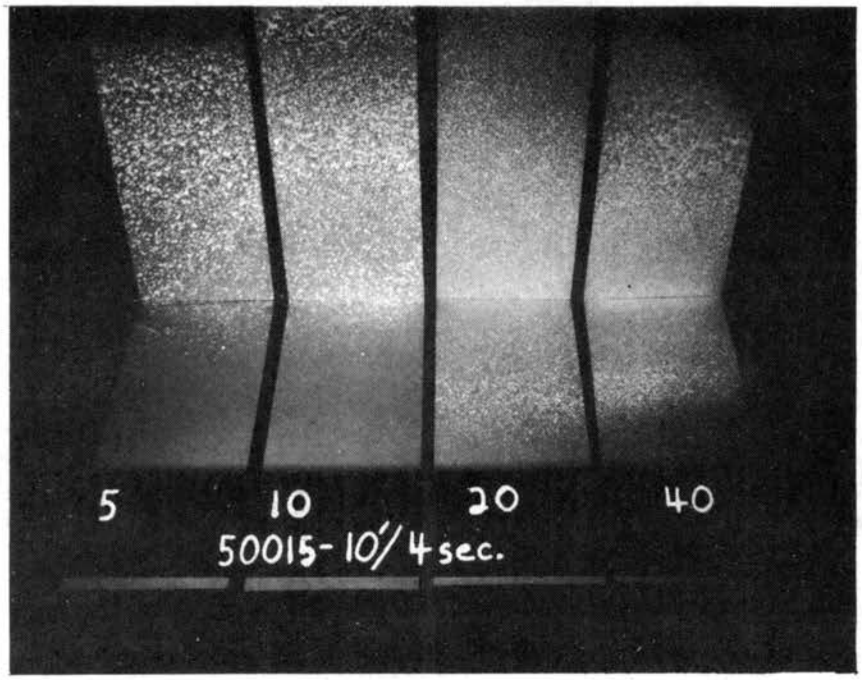

Fig. 11. Spray patterns for nozzle 50015 at 2.5 FPS (10 ft/4 sec) using 5, 10, 20 and 40 psi.

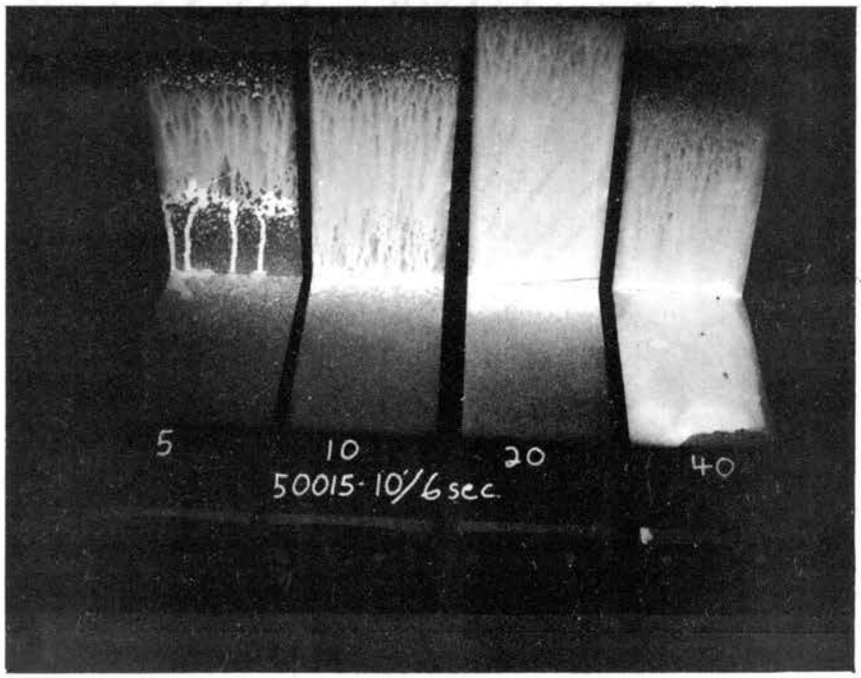

Fig. 12. Spray patterns for nozzle 50015 at 1.67 FPS (10 ft/6 sec) using 5, 10, 20 and 40 psi.

resulting at 40 psi. There was no apparent spray pattern at this operator's speed since runoff was excessive at each application pressure. The amount of solution applied (Table 3) more than doubled at each of the operator's speeds as the pressure of application was increased from 5 psi to 40 psi. From 40 psi at 5 FPS to 40 psi at 1.67 FPS the amount of solution dispensed triples in volume.

In comparing the three nozzles at all speeds and pressures, nozzle 800067 produced the most desirable spray pattern with the least amount of drift and runoff. The operator's speed of 2.5 FPS at 20 psi produced the most desirable spray pattern for nozzles 800067 and 50015. The operator's speed of 5 FPS at 20 psi produced the most desirable spray pattern for nozzle 8002. To avoid excessive drift the application pressure should not exceed 20 psi for any nozzle used.

German Cockroach Mortality and Residual Tests Over a 21 Day Period Using 3 Types of Nozzles at 4 Pressures and 1 Operator Speed

Table 4 represents the total means over 7, 14 and 21 day intervals for the number of cockroaches killed for each nozzle and pressure at one operator's speed. There was a significant difference at the .05 level between pressures using the same nozzle and between nozzles at each application pressure.

In comparing application pressures using nozzle 800067, 40 psi was significantly better than 5 and 20 psi. The application pressures of 5, 20 and 40 psi were significantly better than 10 psi in comparing the application pressures when using nozzle 50015. There was no significant difference between the four pressures when using the 0.2 mm nozzle.

In comparing the 3 nozzles at 4 pressures, nozzle 50015 was significantly better than nozzle 800067 at 5, 20 and 40 psi. All application pressures for the 0.2 mm nozzle were significantly better than 5, 10 and 20 psi for the 800067 nozzle. The application pressure of 10 and 20 psi for the 0.2 mm nozzle was significantly better than 10 psi for the 50015 nozzle.

The differences between nozzles and pressures are illustrated in Fig. 13. A possible explanation for the mean of nozzle 800067 being low is that one of the replicates for this nozzle gave poor results at all application pressures, thus lowering the over-all mean. This was apparently due to a defective nozzle since a different nozzle was used for each replicate with all other factors remaining constant.

The mean number of roaches killed for each nozzle and pressure over 7, 14 and 21 day intervals are given in Table 5. There was a significant difference between time intervals at the .05 level. The means for each time interval from Table 5 were plotted on separate isometric graphs resulting in three dimensional surfaces showing cockroach mortality (Fig. 14, 15, and 16). At the 14 and 21 day test intervals, the mean number of cockroaches killed for nozzle 50015 decreased at the application pressure of 10 psi in comparison to 10 psi at the 7 day interval, while other means stayed relatively constant. This is difficult to explain since all the application factors remained constant for each treatment. The decrease in mortality at 10 psi could be due to the behavioral patterns of the test insects. It was observed that while the cockroaches were on the surface of the previously mentioned treatment there was very little activity in comparison to the other treatments. This could have possibly had some effect on the mortality rate.

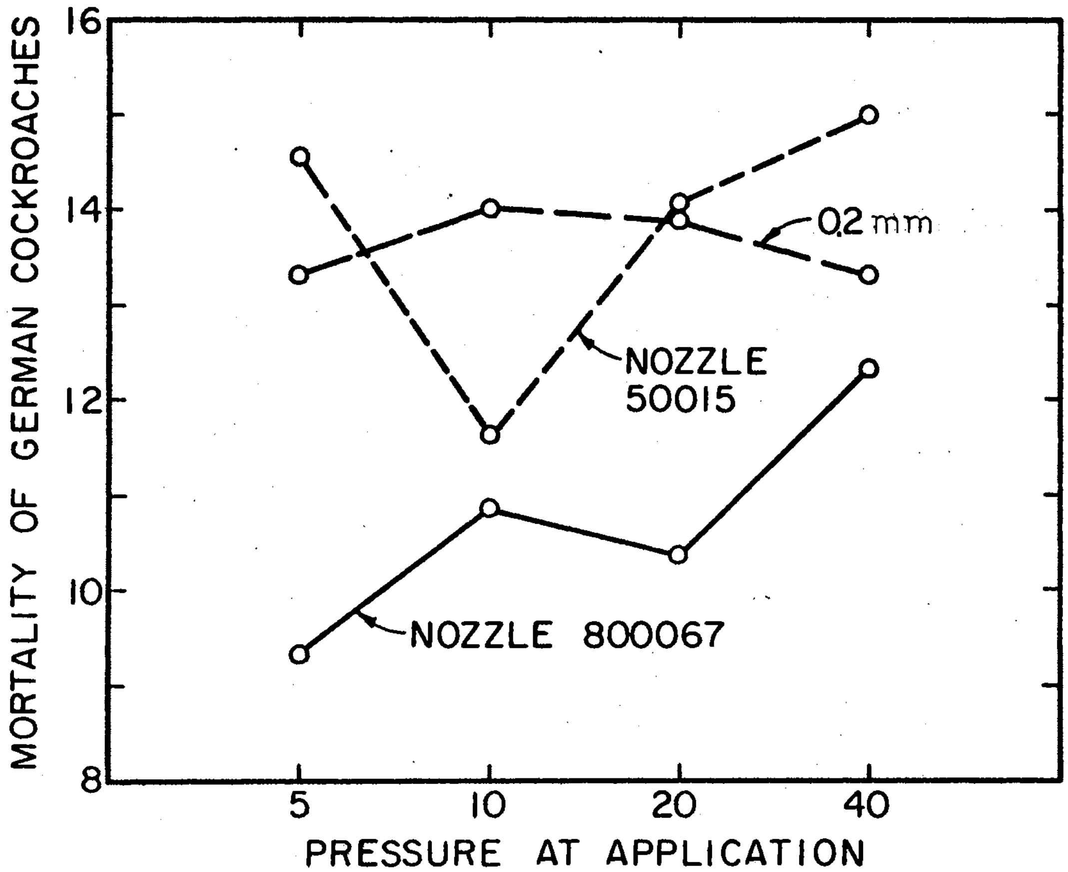

Fig. 13. A graphic illustration derived from table 4 showing total means for Blattella germanica killed over a 21 day interval.

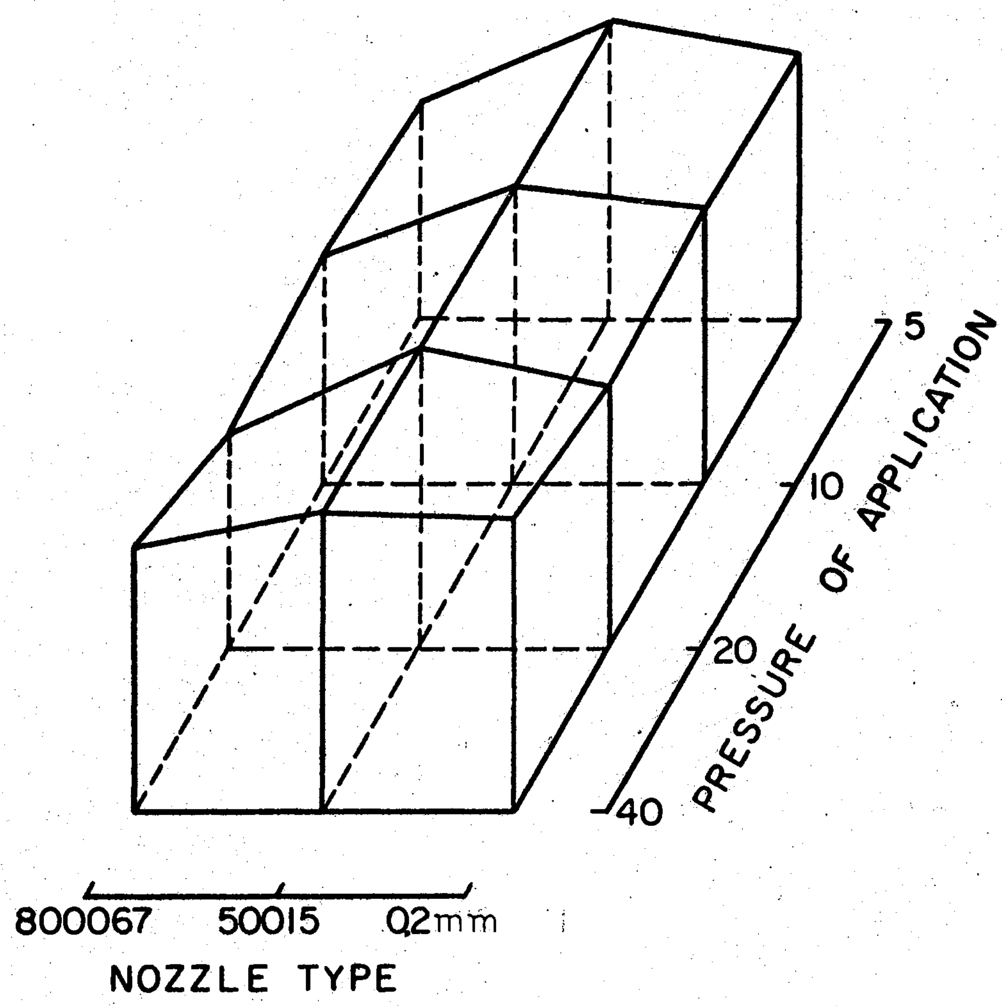

Fig. 14. Three dimensional surface derived from table 5 depicting Blattella germanica mortality 7 days after treatment using the 3 nozzles and 4 application pressures.

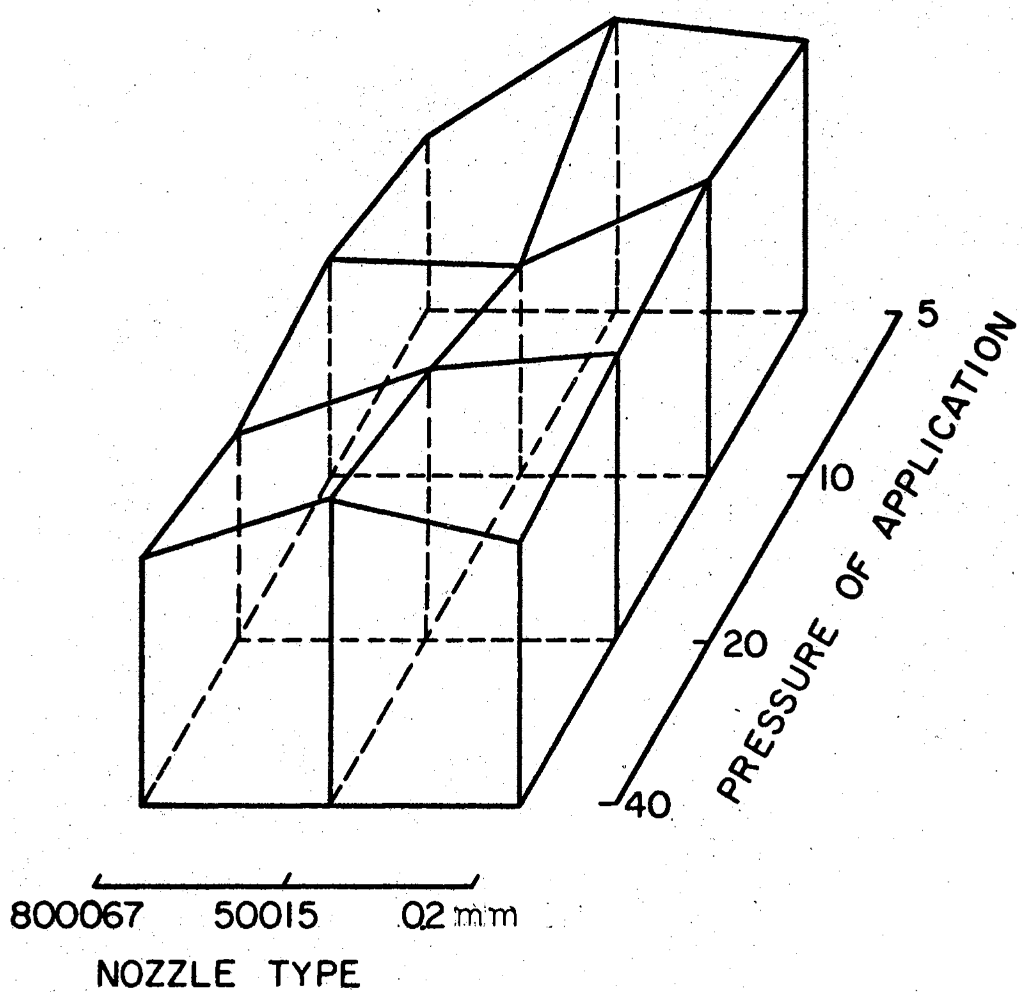

Fig. 15. Three dimensional surface derived from table 5 depicting *Blattella germanica* mortality 14 days after treatment using the 3 nozzles and 4 application pressures.

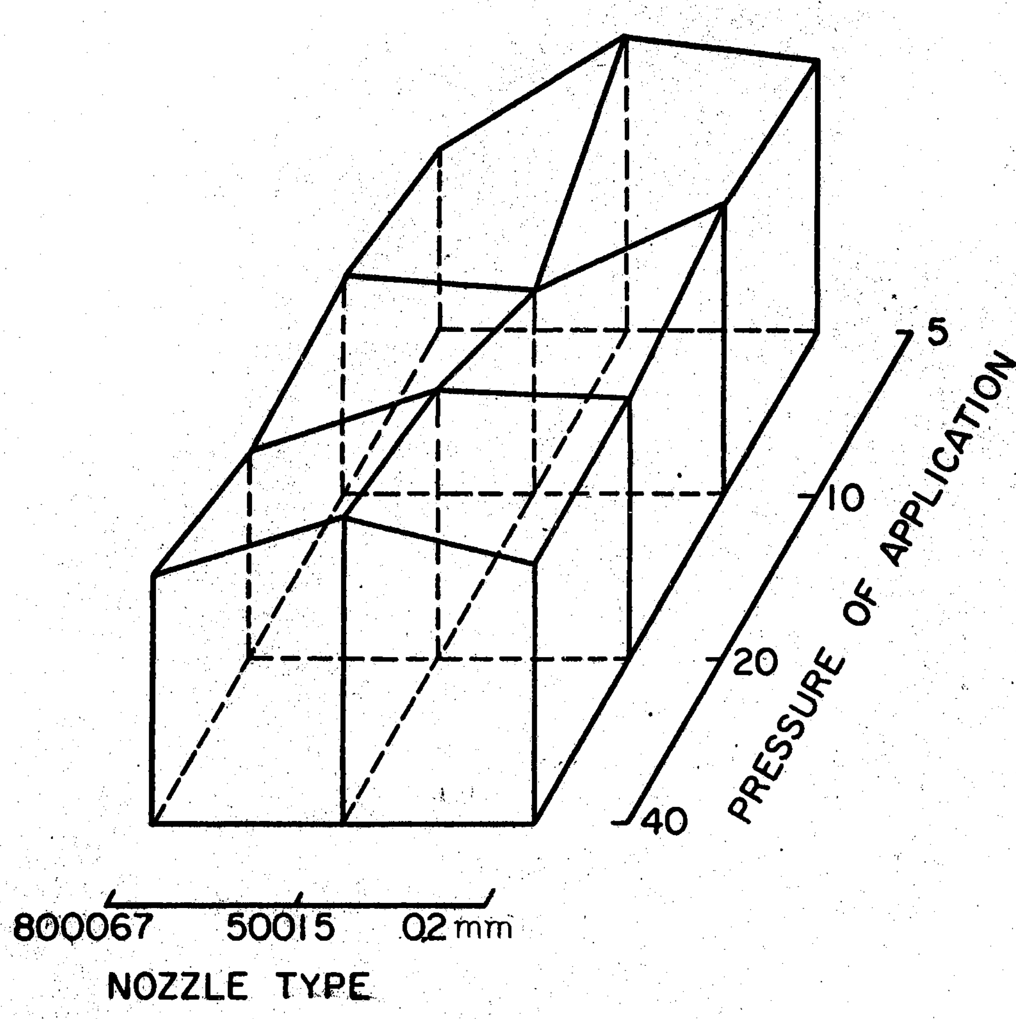

Fig. 16. Three dimensional surface derived from table 5 depicting <u>Blattella germanica</u> mortality 21 days after treatment using the 3 nozzles and 4 application pressures.

Drift Accumulation on the Operator

Preliminary laboratory data from drift studies indicate that when the operator applies an insecticide on a vertical surface, he is very susceptible to spray drift. Figure 17 illustrates drift fallout on the surface of the operator's left shoe. Spray particles on the left half of the shoe have been removed to show the difference that exists. Figure 18 illustrates drift particles which have accumulated on the right hand of the operator. This was the hand used to hold the spray wand during application.

In the same test, many fine droplets were found on the operator's face. The most contaminated area was around the nostrils. A solid line of fluorescent droplets was observed from the upper lip leading into the nasal passage. The nasal hairs were completely coated with the fluorescent drops. This indicates that a large amount of insecticide is probably inhaled by spray operators. These results warrant further research in the area of application safety.

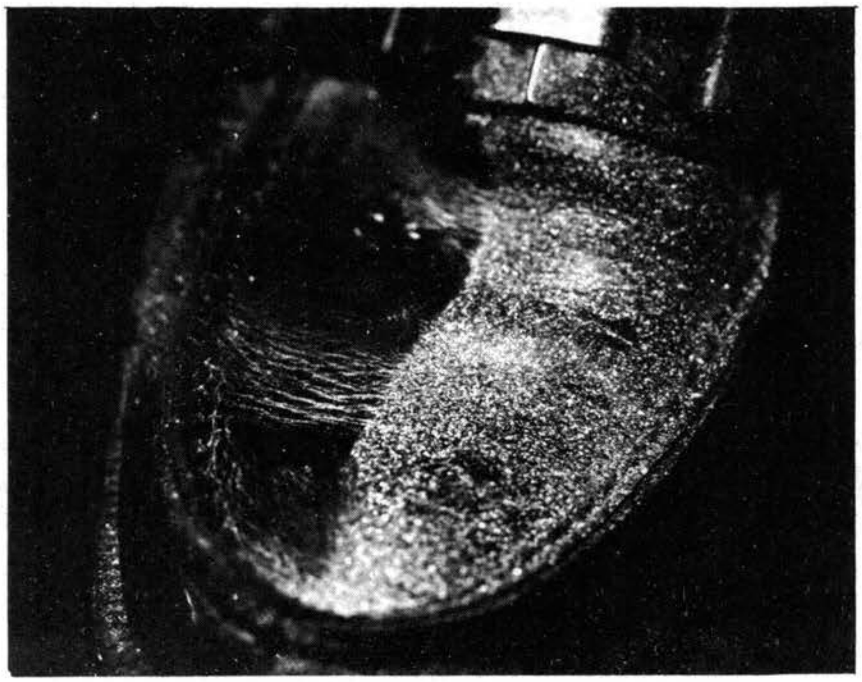

Fig. 17. Accumulation of spray particles on the shoe of the operator while using nozzle 800067 at 2.5 FPS (10 ft/4 sec) at 40 psi.

Fig. 18. Accumulation of spray particles on the right hand of the operator while using nozzle 800067 at 2.5 FPS (10 ft/4 sec) at 40 psi.

SUMMARY AND CONCLUSIONS

Spray Patterns and Drift Studies Using 3 Types of Nozzles at 4 Pressures and 3 Operator Speeds

The operator's speed and nozzle pressure have a direct effect in producing drift and runoff. When the operator's speed is decreased from 5 FPS to 1.67 FPS, the accumulation of drift and runoff increases for the three nozzles tested at all application pressures. This might be eliminated if the operator could refine his spraying techniques to coincide with the speed and pressure of application which gives the most desirable spray pattern for each nozzle. By selecting the desired operator's speed and nozzle pressure, excessive amounts of insecticide and contamination of unsprayed areas could be eliminated.

German Cockroach Mortality and Residual Tests Over a 21 Day Period Using 3 Types of Nozzles at 4 Pressures and 1 Operator Speed

When using nozzle 800067 at 2.5 FPS, the application pressures of 10 and 40 psi gave the best control. In selecting the application pressure for this nozzle, 10 psi would be preferred over 40 psi. At 10 psi there was light drift with no runoff; while at 40 psi there was light drift and light runoff.

In comparing the application pressures for nozzle 50015 at 2.5 FPS, 5, 10 and 40 psi were superior to 20 psi in control of the German cockroach. Application pressures of 5 and 20 psi were more desirable than 40 psi. No runoff or drift was recorded at 5 psi, with only light runoff and drift resulting at 20 psi.

In selecting the application pressure for the 0.2 mm nozzle at 2.5 FPS, there was no significant difference between the application pressures in relation to the mortality of cockroaches. Application pressures of 5 and 10 psi resulted in less runoff and drift and produced a more desirable spray pattern.

The results from this research indicate that in selecting a nozzle and pressure for application of an insecticide three major factors must be considered. The application must give adequate control of the insect with a reduction of runoff and control of drift. The application pressure which gives the best control with the least amount of runoff and drift should be chosen for each nozzle before the application is made.

Drift Accumulation on the Operator

From the preliminary laboratory results, it can be concluded that the operator is susceptible to contamination from drift particles. By reducing the application pressure it is believed less contamination will occur.

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APPENDIX

Table 1. Performance of nozzle 800067 at 4 pressures and 3 operator speeds.

Nozzle Movement FPS	psi	gals/1000 linear ft	Drift	Runoff	Remarks
5	5	.106	none	none	This application
5	10	.132	none	none	speed was considered
5	20	.198	light	none	too fast for the
5	40	.251	light	light	average operator.
2.5	5	.224	none	none	This was considered
2.5	10	.264	none	none	the most desirable
2.5	20	.396	light	none	speed for the average
2.5	40	.502	light	light	operator.
1.67	5	.356	none	none	This speed was
1.67	10	.396	none	none	considered too slow
1.67	20	.554	light	moderate	for the average
1.67	40	.752	light	excessive	operator.

Table 2. Performance of nozzle 8002 at 4 pressures and 3 operator speeds

Nozzle Movement FPS	psi	gals/1000 linear ft	Drift	Runoff	Remarks
5	5	.290	none	none	This was the only
5	10	.343	light	none	speed that
5	20	.488	light	none	did not produce
5	40	.713	light	none	runoff.
2.5	5	.584	none	light	This speed was
2.5	10	.700	light	light	considered undesirable
2.5	20	.977	moderate	moderate	for the average
2.5	40	1.426	excessive	excessive	operator.
1.67	5	.898	none	excessive	This speed was
1.67	10	1.082	moderate	excessive	considered undesirable
1.67	20	1.478	excessive	excessive	for the average
1.67	40	2.033	excessive	excessive	operator.

Table 3. Performance of nozzle 50015 at 4 pressures and 3 operator speeds.

Nozzle Movement FPS	psi	gals/1000 linear ft	Drift	Runoff	Remarks
5	5	.211	none	none	This application
5	10	.277	none	none	speed was considered
5	20	.396	light	none	too fast for the
5	40	.528	moderate	none	average operator.
2.5	5	.422	none	none	This was considered
2.5	10	.554	none	none	the most desirable
2.5	20	.792	light	light	speed for the
2.5	40	1.056	moderate	light	average operator.
1.67	5	.693	none	excessive	This speed was
1.67	10	.818	none	excessive	considered too
1.67	20	1.188	light	excessive	slow for the
1.67	40	1.558	moderate	excessive	average operator.

Table 4. The total means of the test for Blattella germanica[1] killed using 3 types of nozzles at 4 pressures and 1 operator speed.

psi	Nozzles		
	800067	50015	0.2 mm[2]
5	9.2	14.4	13.2
10	10.9333	11.4667	14.
20	10.2	14.0667	13.8
40	12.2667	15.	13.2

[1]Fifteen cockroaches used for each treatment.

[2]Nozzle consisting of four 0.2 mm orifices designed by the Agr. Engr. Dept., Okla. State Univ., Stillwater, Okla.

Table 5. Mean number of Blattella germanica[1] killed at 7, 14, and 21 day intervals using 3 types of nozzles at 4 pressures and 1 operator speed.

psi	Days After Treatment	Nozzles		
		800067	50015	0.2 mm[2]
5	7	10.8	14.8	12.8
10	7	11.6	14.4	13.6
20	7	10.6	15.	14.2
40	7	12.8	15.	14.
5	14	8.4	14.2	13.4
10	14	10.6	10.	14.2
20	14	10.	13.6	14.
40	14	12.	15.	12.8
5	21	8.4	14.2	13.4
10	21	10.6	10.	14.2
20	21	10.	13.6	13.2
40	21	12.	15.	12.8

[1]Fifteen cockroaches used for each treatment.

[2]Nozzle consisting of four 0.2 mm orifices designed by the Agr. Engr. Dept., Okla. State Univ., Stillwater, Okla.

Table 6. Analysis of variance for the mortality of *Blattella germanica* for all intervals.

Variance Source	df	SS	MS	F cal.	F tab (.05)
Corrected Total	179	2193.24444	12.2528		
Rep.	4	501.6889	125.4222		
Nozzle	2	359.0111	179.5056	2.5756	8.65
Error A	8	557.5444	69.6931		
Pressure	3	50.3556	16.7852	2.3893	4.38
Nozzle X Pressure	6	141.7444	23.6241	3.3628	3.35*
Error B	36	252.	7.025		
Time Intervals	2	38.8111	19.4056	8.3966	6.93*
Nozzle X Time	4	15.2222	3.8056	1.6466	5.41
Pressure X Time	6	5.6778	0.9463	.4094	4.82
Error C	96	221.8667	2.3111		
Pooled Error A	8	557.5444	69.6931		
Pooled Error B	36	252.9	7.025		
Pooled Error C	96	221.8667	2.3111		
General Mean		12.6444			
C.V.		0.66023			

*Significant at the 0.05 level of probablity.

Table 7. Analysis of variance for the mortality of *Blattella germanica* 7 days after treatment.

Variance Source	df	SS	MS	F cal	F tab (.05)
Corrected Total	59	800.6	13.5695		
Rep.	4	261.6	65.4	1.692	7.01
Nozzle	2	115.9	57.95	1.499	8.65
Error A	8	309.1	38.6375		
Pressure	3	9.9333	3.111	1.294	4.38
Nozzle X Pressure	6	11.9667	1.9944	.779	3.35
Error B	36	92.1	2.5583		
Pooled Error A	8	309.1	38.6375		
Pooled Error B	36	92.1	2.5583		
General Mean		13.3			

Table 8. Analysis of variance for the mortality of *Blattella germanica* 14 days after treatment

Variance Source	df	SS	MS	F cal	F tab (.05)
Corrected Total	59	679.65	11.5195		
Rep.	4	134.9	33.725	1.74	7.01
Nozzle	2	133.9	66.95	3.45	8.65
Error A	8	155.1	19.3875		
Pressure	3	23.3833	7.7944	1.96	4.38
Nozzle X Pressure	6	89.1667	14.8611	3.73	3.35*
Error B	36	143.2	3.9778		
Pooled Error A	8	155.1	19.3875		
Pooled Error B	36	143.2	3.9778		
General Mean		12.35			

*Significant at the 0.05 level of probability.

Table 9. Analysis of Variance for the Mortality of <u>Blattella germanica</u> 21 days after treatment.

Variance Source	df	SS	MS	F cal	F tab (.05)
Corrected Total	59	674.1833	11.4268		
Rep.	4	128.7667	32.1917	1.68	7.01
Nozzle	2	124.4333	62.2167	3.25	8.65
Error A	8	153.2333	19.1542		
Pressure	3	22.7167	7.5722	1.74	4.38
Nozzle X Pressure	6	89.0333	14.8389	3.43	3.35*
Error B	36	156.	4.333		
Pooled Error A	8	153.2333	19.1542		
Pooled Error B	36	156.	4.3333		
General Mean		12.2833			

*Significant at the 0.05 level of probability.

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VITA

Richard Maurice Rogers

Candidate for the Degree of

Master of Science

Thesis: LABORATORY EVALUATION OF NOZZLES IN RELATION TO SPRAY PATTERNS, DRIFT, AND CONTROL OF THE GERMAN COCKROACH, BLATTELLA GERMANICA (LINNEAUS)

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