



Studies on the factors involved in the use of sodium arsenate dusts against the Mormon cricket  
(*Anabrus simplex* Hald)  
by Ellsworth B Hastings

A THESIS Submitted to the Graduate Committee in partial fulfillment of the requirements for the  
degree of Master of Science in Entomology  
Montana State University  
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**Abstract:**

Evidence is brought out to show that the commercial sodium arsenite used in cricket control probably consists of a mixture of meta sodium, several derivatives of pyro sodium arsenite, and free arsenious oxide. The several diluents under trial were found to be inert when used in connection with cricket dusts and the uniformity of the dust cloud was found to depend largely on the state of subdivision of the particles. A uniform product of sodium arsenite and diluent could be obtained after very short period of mixing. In addition, the jarring of containers did not appreciably alter the concentration of sodium arsenite and diluent either on the top or bottom of the containers.

In treating Mormon crickets, sodium arsenite was found to be effective when applied either as a contact or stomach poison and to be less effective when applied to the tarsi only. It was also found that an increase in temperature would enhance, the killing properties of the dusts both in the case of mature and immature crickets. The removal of dusts from the cricket body even after 90 minutes has lapsed, affects the mortality obtained. Evidence was also presented to show that crickets become inactive after a short time on the surface of a body of water and if allowed to remain there death may occur.

STUDIES ON THE FACTORS INVOLVED IN THE USE OF SODIUM ARSENITE  
DUSTS AGAINST THE MORMON CRICKET (ANABRUS SIMPLEX HALD.)

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ELLSWORTH B. HASTINGS

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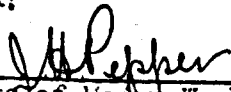
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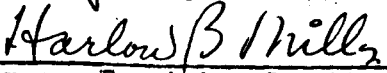
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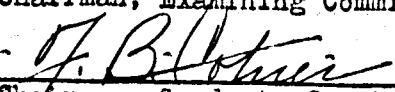
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ABSTRACT

Evidence is brought out to show that the commercial sodium arsenite used in cricket control probably consists of a mixture of meta sodium, several derivatives of pyro sodium arsenite, and free arsenious oxide. The several diluents under trial were found to be inert when used in connection with cricket dusts and the uniformity of the dust cloud was found to depend largely on the state of subdivision of the particles. A uniform product of sodium arsenite and diluent could be obtained after very short period of mixing. In addition, the jarring of containers did not appreciably alter the concentration of sodium arsenite and diluent either on the top or bottom of the containers.

In treating Mormon crickets, sodium arsenite was found to be effective when applied either as a contact or stomach poison and to be less effective when applied to the tarsi only. It was also found that an increase in temperature would enhance the killing properties of the dusts both in the case of mature and immature crickets. The removal of dusts from the cricket body even after 90 minutes has lapsed, affects the mortality obtained. Evidence was also presented to show that crickets become inactive after a short time on the surface of a body of water and if allowed to remain there death may occur.

## INTRODUCTION

During the past two years the control of Mormon crickets (Anabrus simplex Hald.) in Montana as well as in a number of neighboring States, has been one of the major entomological problems. Although Mormon cricket outbreaks have been recorded in earlier times, the first active control campaign in which arsenicals were used to any extent was in 1927. In general the arsenical dusts used during the past two years were the same as those employed in the 1927 campaign. The principal difference has been the change from hydrated lime to diatomaceous earth as the diluent, the latter material causing less discomfort and irritation to the dust gun operators.

Nine hundred tons of mixed sodium arsenite dusts were used in six western States during the 1937, and approximately twice that amount during the 1938 Mormon cricket campaigns. Nearly half of the entire amounts referred to above were used in Montana.

An emergency campaign of this type necessarily leads to many problems concerning the insecticides used, their properties, preparation, and application. Some of the more important problems included a need for a clearer understanding of the chemical composition of the arsenicals used, the physical properties of the dusts, and their possible effects upon the insect.

The following paper is divided into two sections. The first section includes a discussion of the chemistry of sodium arsenite and the physical properties of a number of dusts. The second section deals with the mode of action of the dusts on the Mormon cricket (A. simplex Hald.) and the factors which may influence their toxicity.

ACKNOWLEDGMENTS

The writer wishes to acknowledge his indebtedness to Dr. A. L. Strand for his proposal of the problem, to J. H. Pepper for his continued interest and aid in attacking the problems embodied in this paper, and to Dr. H. B. Mills and D. J. Pletsch for their helpful suggestions and aid in preparing the paper.

## REVIEW OF PREVIOUS WORK

One of the first papers to appear on the use of sodium arsenite in Mormon cricket control was that of Shotwell and Cowan (7). This paper states that when dusting crickets with straight sodium arsenite powder excellent kills were obtained in every instance up to and including twenty feet from the point of application. It further points out the injurious effects to vegetation, wherever present, if straight sodium arsenite is applied.

Cowan (2), a year later, stated that of all the materials tested powdered arsenites of sodium and calcium proved the most effective. He further stated that either of these materials mixed with hydrated lime in the proper proportions and dusted over the swarms was very effective against this insect in almost any stage of its development, that results could be seen in from twelve to twenty-four hours after application, and that the mortality among crickets at the end of a four-day period ranged from 75 to 100 per cent.

Schweis and Burge (6), in connection with their work on Mormon crickets in Nevada, state that upon contact with the insect the lime and sodium arsenite sets up an irritation, causing the cricket to attempt cleaning its antennae and footparts by passing them through its mouth. In this way the arsenic is taken into the stomach, resulting in a slow death which usually occurs between 24 and 48 hours, a certain percentage requiring as high as 170 hours. They further state that moisture in the atmosphere appears to increase effectiveness of the poison, apparently increasing its irritating quality.

Bales (1) published work on substituting diatomaceous earth for hydrated lime as the diluent. He stated that an equal volume (2 pounds) of diatomaceous earth had been substituted for the lime and encouraging results had been obtained. Better dispersal with quicker kill was possible than in the case where lime was used. He further stated that in experimental cages 100% kill had been obtained with 2 pounds of white sodium arsenite and 5 pounds of diatomaceous earth. The rapidity with which the poison killed was greatly increased with temperatures above 90°F.

Glover (3) in his work with the American cockroach (Periplaneta americana (L)), showed that sodium arsenite penetrated the integument of cockroaches much faster than arsenious oxide. His results showed definitely, however, that arsenic would penetrate through the integument of a cockroach to some extent in either form if enough time was allowed. When rather high concentrations are built up in the cockroach body, arsenic may be recovered in all parts and tissues. Such concentrations were found when sodium arsenite was applied as the toxicant, while with the much less soluble arsenious oxide the distribution of arsenic was practically limited to the digestive tract and the parts and tissues near the point of application.



SECTION I

CHEMISTRY OF SODIUM ARSENITE

Sodium arsenite in the dry state may exist as a true compound in any one of the following molecular combinations: Ortho sodium arsenite ( $\text{Na}_3\text{AsO}_3$ ), Pyro sodium arsenite ( $\text{Na}_4\text{As}_2\text{O}_5$ ), or Meta sodium arsenite ( $\text{NaAsO}_2$ ). These substances are believed to ionize when in solution in the following manner: meta ( $\text{NaAsO}_2 \rightleftharpoons \text{Na}^+ + \text{AsO}_2^-$ ); ortho ( $\text{Na}_3\text{AsO}_3 \rightleftharpoons 3\text{Na}^+ + \text{AsO}_3^{--}$ ); pyro ( $\text{Na}_4\text{As}_2\text{O}_5 \rightleftharpoons 4\text{Na}^+ + \text{As}_2\text{O}_5^{--}$ ).

Several methods for the production of sodium arsenite are known and employed. The particular compound used in cricket control is produced by the arsenious oxide - sodium hydroxide method. The difficulty in knowing precisely what form of sodium arsenite is being produced may be readily understood by a study of figure 1 along with its subsequent discussion.

Figure 1 embodies the results of studies made by F.A.H. Shrienmaker and W. C. deBaat as described by Mellor (4) on the system  $\text{Na}_2\text{O}-\text{As}_2\text{O}_3-\text{H}_2\text{O}$  at  $30^\circ\text{C}$ . Here "a" denotes the solubility of  $\text{As}_2\text{O}_3$  in  $\text{H}_2\text{O}$ ; the region abA, the supersaturated solution with  $\text{As}_2\text{O}_3$  as the solid phase; bcB, of the solid phase  $\text{NaAsO}_2$  (meta sodium arsenite); cdC, of the solid  $\text{Na}_4\text{As}_2\text{O}_5 \cdot 9\text{H}_2\text{O}$  (hydrated pyro sodium arsenite); deD, of the solid  $\text{Na}_{10}\text{As}_4\text{O}_{11} \cdot 26\text{H}_2\text{O}$  (a hydrated derivative of pyro); efE, of the solid  $\text{Na}_4\text{As}_2\text{O}_5$  (pyro sodium arsenite); and fgF of the hydrated  $\text{NaOH} \cdot \text{H}_2\text{O}$ . The solubility curve ab shows the rapid increase in the solubility of  $\text{As}_2\text{O}_3$  as the proportions of alkali increase.

Consider the area bcB, wherein the solid material  $\text{NaAsO}_2$  exists.

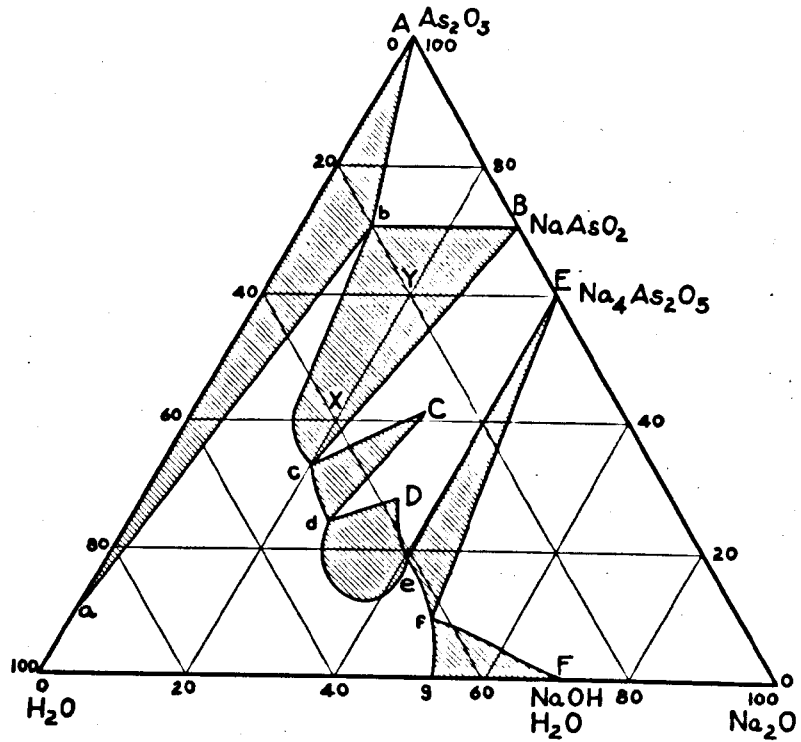


Figure 1. Equilibrium Diagram for the System  $\text{Na}_2\text{O}-\text{As}_2\text{O}_3-\text{H}_2\text{O}$  at  $30^\circ\text{C}$ . (From Mellor (4)).

Any concentrations of the components under equilibrium conditions which fall within this area may be expected to combine to form  $\text{NaAsO}_2$  (meta sodium arsenite). Any point within this area represents the concentrations of the three components,  $\text{As}_2\text{O}_3$ ,  $\text{Na}_2\text{O}$ , and  $\text{H}_2\text{O}$ , necessary for the production of  $\text{NaAsO}_2$ . Take the points X and Y within the aforementioned area. At equilibrium the concentration of the three components are as follows: at X,  $\text{As}_2\text{O}_3$  40%,  $\text{Na}_2\text{O}$  20%,  $\text{H}_2\text{O}$  40%; at Y,  $\text{As}_2\text{O}_3$  60%,  $\text{Na}_2\text{O}$  20%,  $\text{H}_2\text{O}$  20%. Only under equilibrium conditions is it possible to obtain the pure compound as indicated in the shaded areas. Otherwise, mixtures of unknown proportions may be obtained.

A. Stavenhagen, according to Mellor (4), produced sodium arsenite  $\text{Na}_3\text{AsO}_3$  by heating finely powdered  $\text{As}_2\text{O}_3$  with an excess of an alcoholic solution of  $\text{NaOH}$ , and B. L. Vanzetti made sodium ortho arsenite by reacting on  $\text{As}_2\text{O}_3$  with sodium methoxide in accordance with the following equation:  $\text{As}_2\text{O}_3 + 6\text{NaOCH}_3 = 2\text{Na}_3\text{AsO}_3 + 3(\text{CH}_3)_2\text{O}$ . Neither of the above methods are used to any extent in the production of sodium arsenite for insecticidal purposes.

The finely powdered oxide ( $\text{As}_2\text{O}_3$ ) is not easily wetted by water, but a solution can be prepared by boiling. It also dissolves in warm sodium bicarbonate solution, with evolution of  $\text{CO}_2$ , and formation of either or both the meta and ortho sodium arsenites,  $\text{Na}_3\text{AsO}_3$  or  $\text{NaAsO}_2$  respectively, depending on the equilibrium conditions.

The sodium bicarbonate method is used for the preparation of the sodium arsenite employed in the standard stock dip against Rocky Mountain spotted fever tick (*Dermacentor andersoni*). It is not known

whether the product obtained is ortho or meta or a mixture of the two sodium arsenites. The exclusive use of this product in dipping stock may possibly be due to the fact that it has proven successful in controlling ticks without injury to the stock. Also, with the possibility of serious injury to stock from burning in mind, work with sodium arsenite manufactured by other methods has not been undertaken.

In evaluating sodium arsenite for insecticidal purposes, it is customary to consider the  $As_2O_3$  content. On the basis of equivalents the sodium arsenite compounds so far mentioned in this paper contain the following percentages of  $As_2O_3$ : ortho sodium arsenite ( $Na_3AsO_3$ ) 73.84%; meta sodium arsenite ( $NaAsO_2$ ) 76.15%; pyro sodium arsenite ( $Na_4As_2O_5$ ) 61.49%; hydrated pyro sodium arsenite ( $Na_4As_2O_5 \cdot 9H_2O$ ) 41.25%; and the solid ( $Na_{10}As_4O_{11} \cdot 26H_2O$ ) 34.38%.

The specifications for the dry sodium arsenite used in the recent cricket campaigns called for not less than 80%  $As_2O_3$  content. By reference to the previous discussion of  $As_2O_3$  contents of sodium arsenite compounds, it will be seen that none of the established formulae of the true chemical compounds contain such a high percentage of  $As_2O_3$ . The pure meta sodium arsenite comes nearest to meeting the specifications, but in view of the fact that the sodium arsenite manufactured for cricket dust is a mixture of the several sodium arsenites, all containing less than 76.15%  $As_2O_3$ , it is reasonable to assume that the additional  $As_2O_3$  content is added as  $As_2O_3$  to meet the required specifications.

With reference to L. C. Glover's (3) work on the penetration of certain arsenical compounds into the body of the American cockroach

(Periplaneta americana (L) ), wherein he showed the highly insoluble  $\text{As}_2\text{O}_3$  to be much less permeable to the insect integument than sodium arsenite, it would appear that the value of arsenious oxide as a dust is questionable. One may assume then that the  $\text{As}_2\text{O}_3$ , as such, when added to cricket dust strengthens the insecticidal powers of the material only very slightly.

A letter received from the Chipman Chemical Company, from whom the greatest portion of the sodium arsenite used in the 1938 cricket campaign was purchased, describes their product as follows: "Mostly  $\text{Na}_2\text{H}_4\text{As}_4\text{O}_9$  with possibly some  $\text{NaH}_2\text{As}_3\text{O}_6$ . . . . Our product is thought to be largely the ortho arsenite but containing an excess of  $\text{As}_2\text{O}_3$  over the normal ortho product".

No doubt these formulae were derived from an analysis of the product. However, in deriving them from a mixture of sodium arsenite and  $\text{As}_2\text{O}_3$ , it appears more probable that the basic material is the meta rather than the ortho sodium arsenite. Starting with the meta arsenite  $\text{NaAsO}_2$  and adding one molecule of  $\text{As}_2\text{O}_3$  and one molecule of  $\text{H}_2\text{O}$ , the formula  $\text{NaH}_2\text{As}_3\text{O}_6$  resolves itself. Likewise, starting with  $\text{NaAsO}_2$  and adding another molecule of this compound plus one molecule of  $\text{As}_2\text{O}_3$  plus two molecules of water, the compound  $\text{Na}_2\text{H}_4\text{As}_4\text{O}_9$  is obtained. No evidence can be found to show that  $\text{Na}_2\text{H}_4\text{As}_4\text{O}_9$  is a true compound. In all probability it is a mixture of meta sodium arsenite,  $\text{As}_2\text{O}_3$ , and water.

#### TIME OF MIXING

A modification of the standard iodine titration method for determining arsenic was used (5). Since it was not possible to ascertain

the exact chemical composition of the sodium arsenite employed in the experiments, the value of the standard iodine was calculated in terms of sodium arsenite instead of the  $\text{As}_2\text{O}_3$  content. This necessitated repeated standardizations throughout the entire series of experiments.

To determine the effect of the diluents on the titration procedure, a series of weighed samples of sodium arsenite were intimately mixed with the carriers and titrated. Table I embodies the results obtained. The amount of sodium arsenite recovered in each titration proves the method to be well within experimental error.

The question has often arisen as to the length of time necessary to mix sodium arsenite and carrier to obtain a uniform mixture.

To obtain an indication of the uniformity of the dust used in the field, eleven samples of 1 gram each were removed from drums of mixed dusts and titrated. The dust had been mixed for 20 minutes in a power mixer, and the original proportions introduced were approximately 3 to 1 diatomaceous earth and sodium arsenite. The samples showed the following proportions by weight of the diatomaceous earth to one part of sodium arsenite: 3.42, 3.35, 3.11, 3.13, 2.78, 2.34, 3.24, 3.48, 3.62, 2.01, 3.68. The average for the 11 samples was 3.07.

Table II shows the results obtained when 1 gram samples of dust were removed from each of two different types of mixers, ball mill and field mixers, at stated intervals and titrated. The ball mill was the common laboratory type of one gallon capacity which revolved at the rate of 66 revolutions per minute. The field mixer was a power driven custom built drum which was set on an eccentric. The drum revolved 15 times per minute and had a capacity of approximately 400 pounds.

TABLE I.-Results of the determination of a known quantity of sodium arsenite in the presence of a 3:1 mixture of various dusts, by the titration method.

Diluent	Weighed amount of Sodium Arsenite in mg.	Mg. of sodium arsenite determined by titration	Average
Sodium Arsenite	100	99.65	99.94
	100	100.40	
	100	99.65	
	100	99.95	
	100	99.57	
	100	99.70	
	100	100.45	
	100	100.06	
Sodium Arsenite + Diatomaceous Earth	100	98.61	98.73
	100	97.89	
	100	99.09	
	100	99.33	
Sodium Arsenite + Celite	100	99.95	99.88
	100	100.25	
	100	99.95	
	100	99.35	
Sodium Arsenite + Hydrated Lime	100	98.90	99.21
	100	99.00	
	100	99.00	
	100	99.95	
Sodium Arsenite + Calcium Carbonate	100	99.65	99.91
	100	99.65	
	100	100.10	
	100	100.25	
Sodium Arsenite + Bentonite	100	100.53	99.57
	100	99.33	
	100	99.09	
	100	99.33	
Sodium Arsenite + Volcanic Ash	100	97.50	98.41
	100	101.20	
	100	98.40	
	100	96.55	

TABLE II.-Proportion by weight of diatomaceous earth to one part of sodium arsenite as determined by one gram samples taken from mixers at the time intervals noted.

Time in minutes	Proportions by weight of D. earth to 1 part sodium arsenite			
	Ball Mill		Field Mixer	
	Sample 1	Sample 2	Sample 1	Sample 2
5	4.74	4.85	3.35	3.48
10	3.28	3.77	2.78	3.30
15	3.54	3.54	1.96	3.18
20	3.50	3.72	2.56	3.04
25	3.58	3.61		
30	3.52	3.49		
40	3.44	3.45		
50	3.40	3.28		
60	3.36	3.57		

It will be noted that a fairly constant mixture was obtained in samples taken from the ball mill after a ten-minute period. Samples from the field mixer proved to be somewhat more erratic, although with the exception of one sample all approached a 3 to 1 mixture after five minutes. This indicates that prolonged periods of mixing are not necessary to obtain a reasonably uniform product.

#### CARRYING PROPERTIES OF DILUENTS

One of the problems to be considered in connection with field applications of dusts was the width of swath within which an approximate 3 to 1 concentration of diluent and sodium arsenite existed. The wind velocity as well as the force applied at the nozzle would, of course, have a direct influence on the problem. Inert material added to the sodium arsenite had been thought to act both in the role of carrier for the active



ingredient and as a diluent. Also, any part of the dust cloud was considered to contain an approximate 3 to 1 mixture. The errors in these conceptions will be pointed out in the following work.

A series of experiments was planned with the object in mind of obtaining a clearer picture of the role of the inert ingredient, as well as some definite knowledge as to the concentration of sodium arsenite throughout the dust cloud. The work was done in a room approximately 25 feet long and 10 feet wide which was tightly closed to eliminate any possible effects from air currents other than those caused by the small dust nozzle. From observations made on the dust cloud, other air currents present appeared insignificant.

Mixed dusts were blown out from a nozzle held two feet above and one foot back of the first of a series of petrie dishes, placed one foot apart for a distance of 14 feet.

The dust nozzle which was used applied the principle of the Venturi tube. It was constructed of a 12-inch piece of 6 mm. glass tubing constricted in the center at which place a piece of 3 mm. glass tubing was sealed. A constant air pressure was applied to the larger tube, thus creating a vacuum in the smaller one. During dusting operations the end of the small tube was kept immersed in a vessel of the dust. A quite uniform finely divided dust cloud was obtained.

After a heavy cloud had been blown out over the petrie dishes, the dust was allowed to settle until the air was clear. The samples obtained in this manner were then weighed and titrated to determine the proportions of sodium arsenite and inert material.

The original concentration by weight of the material as it left

the dust nozzle was in the proportion of three parts inert ingredient to one part commercial sodium arsenite.

Table III, represented graphically in figures 2 and 3, embodies the results obtained from the foregoing experiments. Table IV lists some physical aspects of the diluent used. Photomicrographic pictures of each diluent will be found in figure 4.

Consider the curve for diatomaceous earth as shown in figure 2. It will be noted that a number of samples near the nozzle contained a higher proportion of sodium arsenite than of the inert ingredient, thus indicating that a large percentage of the sodium arsenite had fallen out of the mixture near the source. A 1 to 3 mixture of sodium arsenite and inert ingredient was obtained at a point approximately  $9\frac{1}{2}$  feet from the nozzle. From this point out the curve rises abruptly showing a very dilute dust, as a consequence of previous rapid settling of sodium arsenite.

Compare the curve for diatomaceous earth with that of celite in figure 3. It will be noted in the case of celite that a 1 to 3 mixture was not obtained in any of the samples taken but was approached in the final sample. All the samples taken were more highly concentrated than the original mixture of 1 to 3. It was presumed that the theoretical portion of the curve as continued from the final sample, would rise abruptly in view of the fact that the greater portion of sodium arsenite had fallen out.

The two substances thus far considered have nearly the same densities, and these densities more nearly approach that of sodium arsenite than any of the other inert materials used. This may be seen by reference to Table IV. If the density of the inert ingredient was the factor in

TABLE III.--Proportions by weight of the diluent to one part of sodium arsenite as determined from samples collected at various distances from the dust nozzle.

Distance in feet	Diatomaceous earth	Celite	Volcanic ash	Hydrated lime	Bentonite	Calcium carbonate
1	1.52	0.88	1.36	1.68	2.89	0.90
2	0.55	1.21	1.69	1.89	2.53	0.97
3	0.49	1.50	2.38	2.19	2.46	0.91
4	0.71	1.68	3.55	2.22	3.17	1.88
5	0.97	1.49	4.32	2.26	3.73	2.88
6	2.21	1.26	4.16	2.27	3.94	3.57
7	1.20	1.38	4.21	2.33	3.84	4.73
8	1.83	1.44	3.84	3.14	3.71	4.23
9	1.03	1.87	4.02	2.67	3.71	4.39
10	--	1.79	3.54	1.99	3.47	4.32
11	3.04	2.09	3.36	2.22	3.63	4.37
12	8.11	2.23	3.12	1.87	3.57	4.20
13	9.12	2.61	2.76	2.16	4.12	4.01
14	12.90	2.62	2.36	1.63	3.58	4.03

TABLE IV.--Some physical aspects of the diluents used.

Material	Degree of Subdivision	Density
Sodium Arsenite	Very fine	1.87
Diatomaceous Earth	Moderately fine	1.96
Celite	Very fine	1.99
Hydrated Lime	Very fine	2.20
Bentonite	Moderately coarse	2.49
Volcanic Ash	Coarse	2.59
Calcium Carbonate	Moderately fine	2.70

determining its so-called carrying properties, one might then expect to obtain a straight line, or nearly so, superimposed on the horizontal line which represents a 1 to 3 mixture in figures 2 and 3. It is obvious that this type of curve was not obtained in either the case of diatomaceous earth or celite.

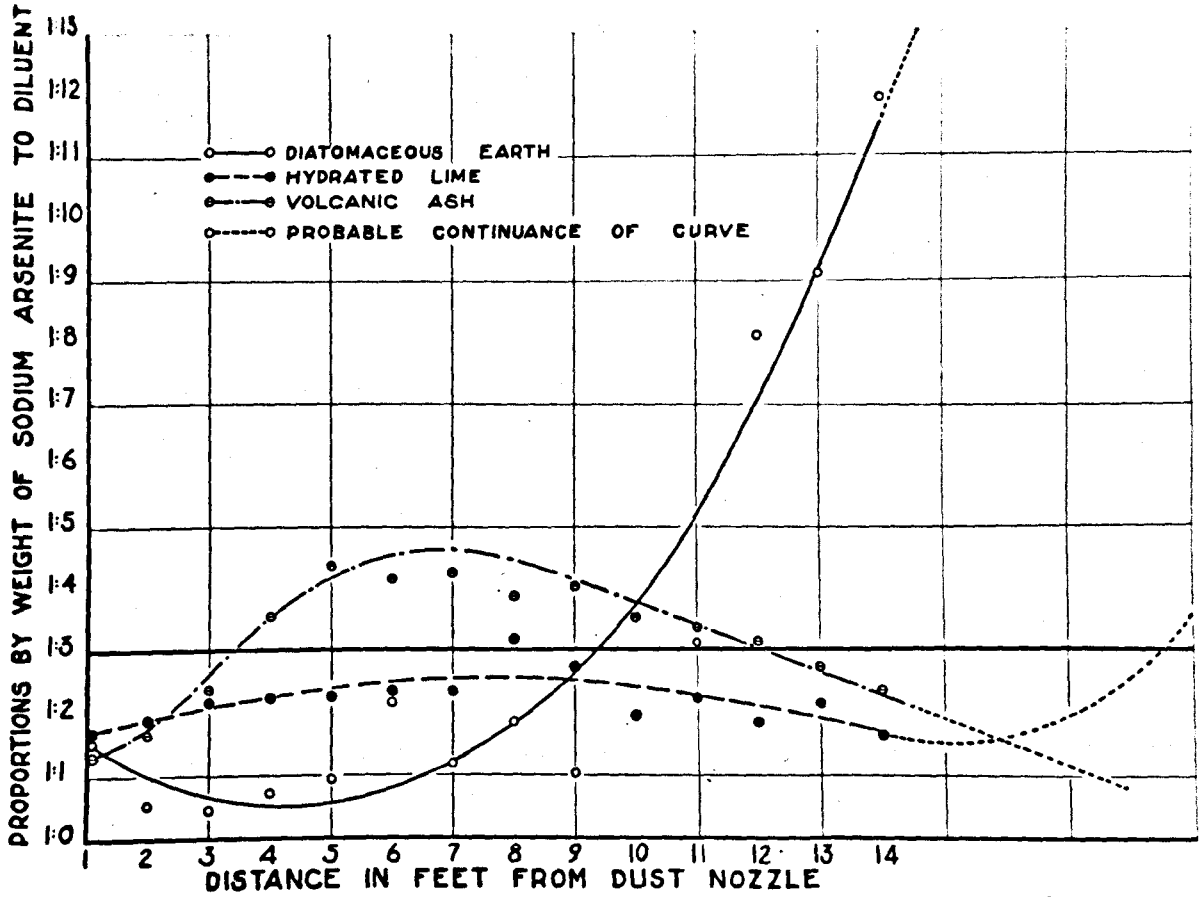


Figure 2. Settling curves for diatomaceous earth, hydrated lime, and volcanic ash.

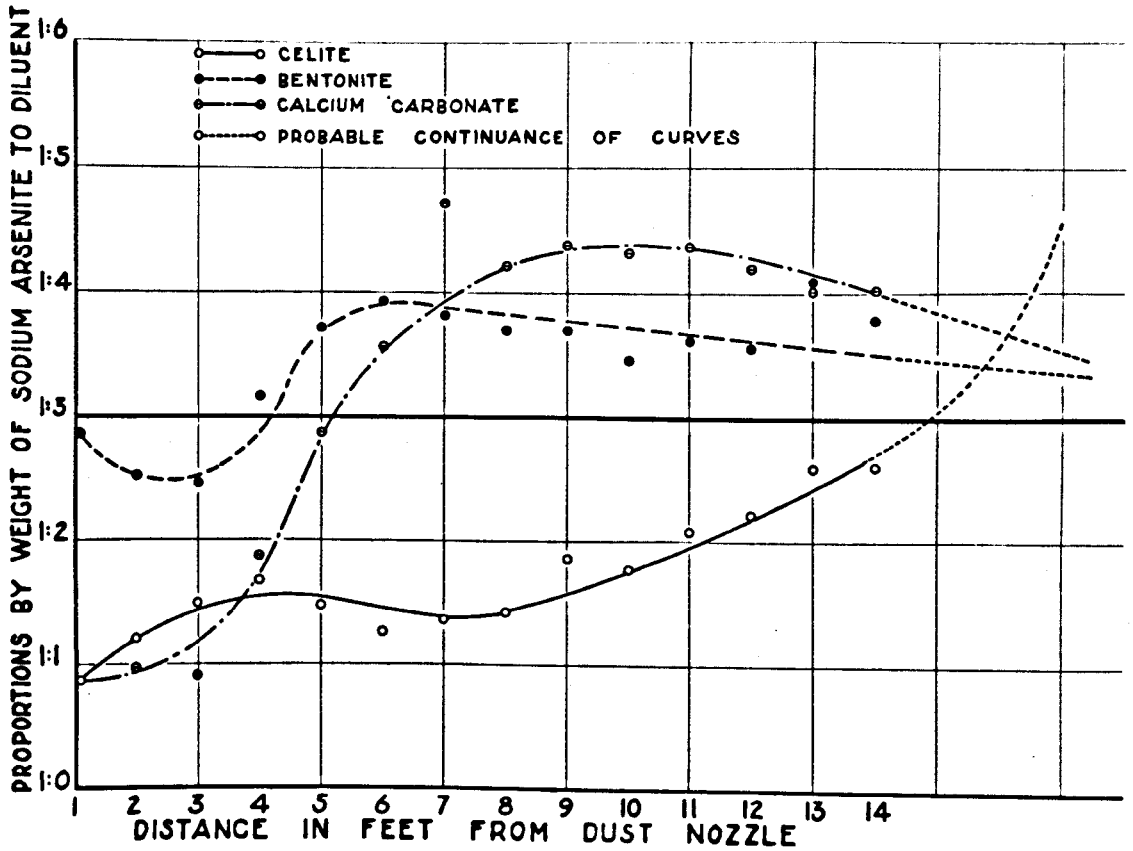
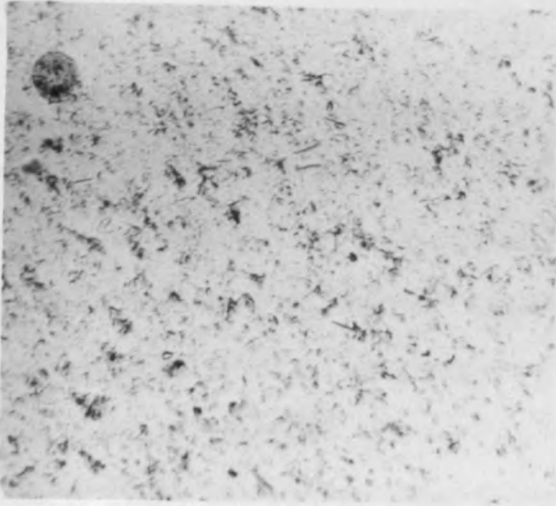
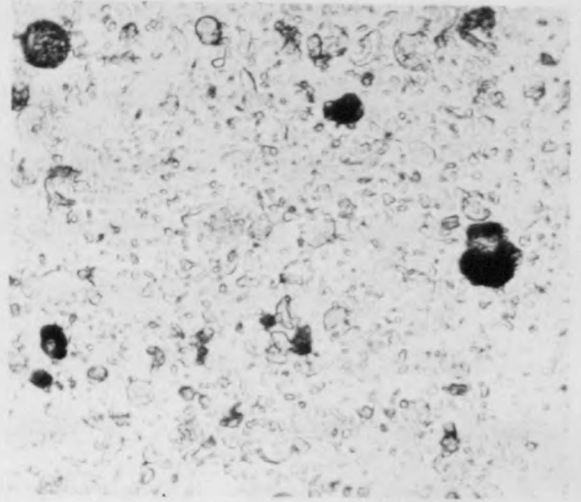


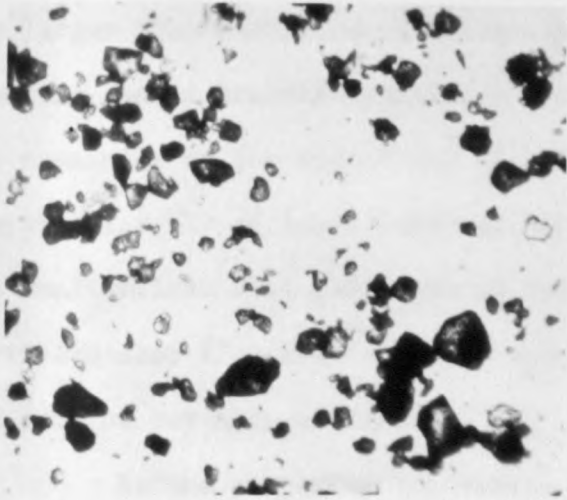
Figure 3. Settling curves for celite, bentonite, and calcium carbonate.



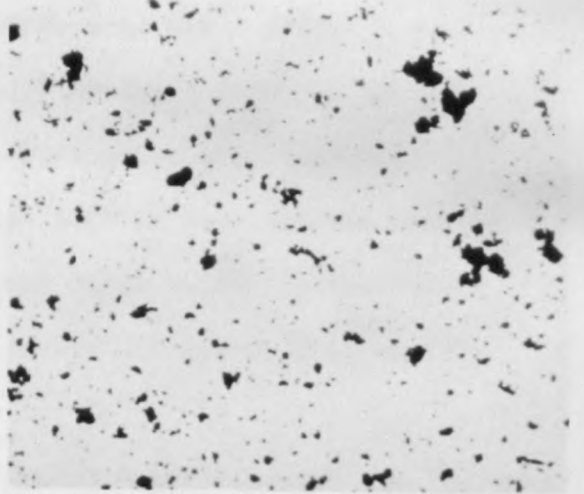
Celite



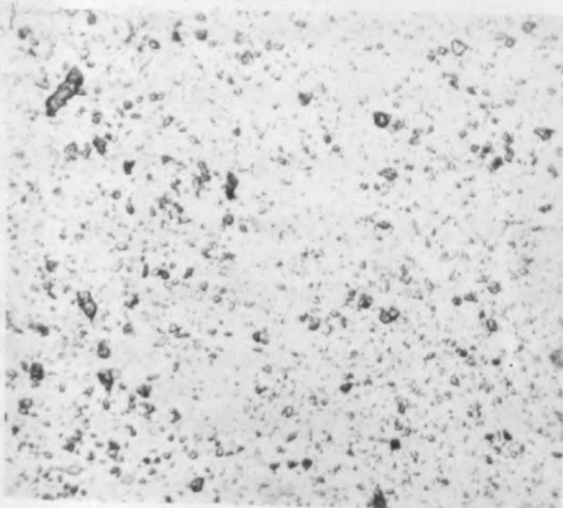
Diatomaceous earth



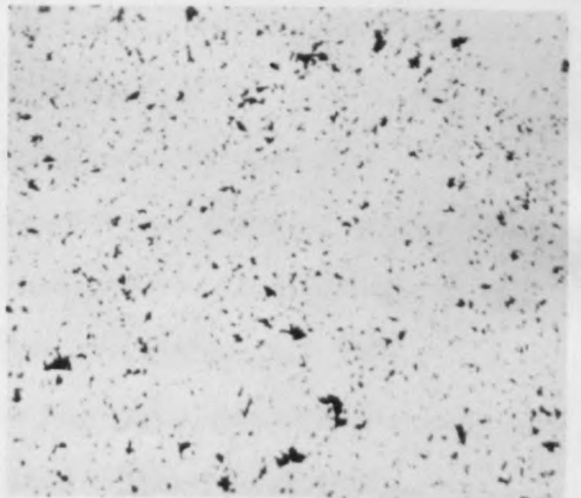
Volcanic ash



Bentonite



Calcium carbonate



Hydrated lime

Figure 4. Photomicrographs of the diluents.

Consider the photomicrographs of these two substances in figure 4. It will be noted that both substances contain irregular particles of somewhat similar pattern. With the exception of particle size, both appear to be somewhat alike. The particles composing diatomaceous earth are large and many of them flat, while those of celite are considerably smaller and less flat in character. Both substances appear extremely light and fluffy under a binocular microscope. Referring again to the curves of the two substances in figures 2 and 3, it would appear that the larger flat particles of diatomaceous earth were blown abruptly away from the sodium arsenite particles for a short distance from the nozzle. The remainder of the dust cloud past the  $9\frac{1}{2}$  foot point was consequently composed largely of inert material which then settled out. In the case of the smaller, less flat particles of celite, the curve indicates that these particles also blew away from the sodium arsenite but did so less rapidly and settled out more uniformly.

Before comparing the curves for bentonite and volcanic ash, figures 2 and 3, a description of these materials will be given. Bentonite, a finely divided clay, was obtained in the vicinity of Hardin, Montana, and volcanic ash, a finely divided product containing a high per cent. of silica, was obtained near Big Timber, Montana. Both substances have densities very much alike, and their densities are half again greater than those of either celite, diatomaceous earth, or sodium arsenite. With reference to figure 4, it will be seen that volcanic ash is composed of extremely coarse sand-like particles, irregular in size and shape. The bentonite, while only moderately coarse, is also composed of irregular particles slightly less angular in

character than volcanic ash.

It will be noted that there is a certain similarity in the two curves. Both rise abruptly between 3 and 6 feet from the dust nozzle and then tend to approach the 1 to 3 mixtures. It would appear from the curve for volcanic ash that the large heavy particles of this material are blown out away from the sodium arsenite particles only a very short distance. The abrupt rise of the curve from the 3 foot point to a concentration of approximately 1 to 4.5 sodium arsenite to volcanic ash indicates a dilute dust. Within this portion of the curve the inert material settles out quite rapidly. At a point 12 feet from the nozzle, a 1 to 3 mixture again occurs. From here on out a concentrated mixture is obtained, due to the fact that the greater portion of inert material has settled out before reaching this point. The curve for the somewhat more finely divided bentonite follows the same general trend as that of volcanic ash. However, after the abrupt rise the curve does not descend as rapidly as that of the former. This indicates that a more uniform settling out of the inert material occurred than in the case of the larger particles of volcanic ash.

Now consider the settling curve for calcium carbonate as shown in figure 3. This material has the greatest density of any of the inert materials under trial. It is composed of moderately fine, regular, non-angular particles, and as shown in Table IV it is more finely divided than volcanic ash or bentonite, which also have high densities. From a study of the curve for calcium carbonate, it will be seen that the moderately fine particles of the inert materials are blown away from the sodium arsenite for a distance of approximately  $4\frac{1}{2}$  feet. The samples obtained



show a 1 to 3 mixture at about 5 feet from the nozzle. It may be seen that the maximum settling out of inert material was somewhat farther from the nozzle than it was in either the case of volcanic ash or bentonite. The degree of subdivision of the particles is held responsible for this occurrence in view of the fact that the calcium carbonate is heavier than either of the two above mentioned diluents. All samples obtained from 6 to 14 feet from the nozzle were very dilute. In view of this fact, the theoretical portion of the curve is presumed to again approach a 1 to 3 mixture.

The last settling curve to be considered is that of hydrated lime. This substance consists of very finely divided, regular, non-angular material slightly heavier than sodium arsenite. Hydrated lime appears to agglomerate somewhat and in doing so gives the material the appearance of being composed of about an equal number of very fine and moderately fine particles. The formation of these agglomerations leads to a possible explanation of the curve as shown in figure 2.

This curve more nearly approaches what may be considered the ideal curve, a straight line superimposed on the horizontal line representing a 1 to 3 mixture, than any of the other curves in figures 2 or 3.

Since the hydrated lime is somewhat heavier than sodium arsenite, it may be presumed that as the dust leaves the nozzle the large agglomerates of inert material begin settling out simultaneously with the sodium arsenite. The smaller particles of lime are then blown farther out from the nozzle and do not begin settling out until most of the large agglomerates have settled. The smaller particles then start settling out at about the same rate that the larger particles had previously settled out, thus keeping the

samples rather uniform. Throughout the entire curve it may be seen that the sodium arsenite settled out of the dust cloud slightly faster than did the inert ingredient.

It is presumed that the theoretical portion of the curve would rise above the 1 to 3 base line at some point past the place where the last sample was taken. This rise may be attributed to the fact that a large proportion of the samples were more concentrated than the original 1 to 3 mixture, and a cloud of very finely divided lime was suspended in the air past the 14 foot point.

It may be seen by a consideration of the entire series of settling curves that the proportion of sodium arsenite and inert ingredient does not remain the same throughout the whole of the dust cloud. The sodium arsenite and the inert ingredient apparently settle out independently of each other, thus showing the inert substance to act solely in the role of a diluent. It is apparent that the density of the diluent does have some effect on the ability of its particles to stay in suspension in air. It is believed, however, that the principle factor in determining the uniformity of a dust cloud is the degree of subdivision of the particles. Under certain conditions, then, one may expect to obtain what is considered to be a lethal dust in the case of diatomaceous earth only about as far from the dust nozzle as the straight sodium arsenite could be blown.

#### JARRING EFFECTS ON MIXED DUSTS

Tables V and VI embody the results of experiments which arose from

the need to determine the effect on the concentration of the dusts while trucking drums of the mixed substances from a central mixing station to field stations. Some workers in the field have presumed that the dust taken from the top of the drum was more dilute than that obtained from near the bottom.

An apparatus was constructed to as nearly simulate the jarring action of a moving truck as was possible. It was made in the following manner. A 5 foot board was mounted on a platform, hinged at one end, and rested on a piece of rubber sponge at the other end. An electric motor equipped with a hardwood eccentric wheel attached to the shaft was bracketed to the platform. The eccentric wheel was allowed to rest on the upper side of the board with sufficient pressure to cause a slight compression of the rubber sponge. A sharp jarring motion was obtained with each revolution of the wheel. The speed of the motor could be regulated as desired. Uprights, to which two settling tubes 4 feet long and 5 cm. in diameter could be securely clamped, were attached to the board.

The settling tubes were filled to a height of 2 feet with a 3 to 1 mixture of the dusts, and the samples removed from the bottom of the column at the time intervals noted in Table V. Two diluents, one very dense and the other very light were used, and the experiments done in duplicate.

It will be noted that no appreciable change in concentration was found in any samples obtained even after jarring had been continued for one hour.

Table VI shows the results of titrations as obtained when 1 gram samples of dust were taken from the top of a column of dust after jarring for the time intervals noted. The same apparatus and dusts were used in

TABLE V.-Proportion by weight of the diluent to 1 part of sodium arsenite as determined from samples taken from the bottom of a column of dust after vibration for the time intervals noted.

Time in minutes	Proportions by weight of diluent to 1 part sodium arsenite			
	Diatomaceous earth		Volcanic Ash	
	Sample 1	Sample 2	Sample 1	Sample 2
5	3.1	3.1	2.9	2.9
10	3.1	3.0	2.9	2.9
15	3.0	2.9	2.9	2.9
20	2.9	2.8	2.9	2.8
25	2.8	2.8		
30	2.8	2.7	2.8	2.8
35	2.8	2.7		
40	2.7	2.7	3.9	2.8
50	2.7	2.6	2.7	2.6
60	2.6	2.6	2.8	2.8

TABLE VI.-Proportion by weight of the diluent to 1 part of sodium arsenite as determined from samples taken from the top of a column of dust after vibration for the time intervals noted.

Time in minutes	Proportions by weight of diluent to 1 part sodium arsenite			
	Diatomaceous earth		Volcanic ash	
	Sample 1	Sample 2	Sample 1	Sample 2
15	3.1	2.7	3.3	3.4
30	2.3	3.1	2.7	3.2
45	3.4	3.5	1.9	3.1
60	2.0	3.6	2.5	3.0

this experiment as were used in the previous experiment except that liter beakers were substituted for the settling tubes.

It will be noted that the results obtained in this experiment

were somewhat more erratic than those of the previous one. However, the samples from the top of the containers after prolonged jarring show no tendency to become either more concentrated or more dilute to any great extent.

## SECTION II

### PERMEABILITY AND ITS CONTROLLING FACTORS

In introducing the problems considered in the following section of this paper, it is deemed advisable to enter into a brief discussion of some of the possible factors which may influence the results obtained.

It is generally recognized that an insecticide, to exhibit toxic effects, must enter the cells of the insect. The foregoing statement applies to the so-called stomach poisons as well as to the contact poisons. If the walls of the alimentary tract did not permit the toxic material to enter the cells, the material would be expected to pass through the insect with no injurious effects. For instance, arsenious sulphide, a highly insoluble but toxic material, when administered as a stomach poison, exhibits no toxic effects whatever. Also, arsenic, when used as an insecticide, is known to attack the nervous system of the insect. Therefore, it must enter the cells, as the nervous system is not believed to be exposed, either on the outer surface or in the alimentary tract of the insect. If the nervous system were exposed the material would still have to penetrate a cell membrane in order to enter.

All permeability control is presumed to lie primarily in the outer plasma membrane of the cell. The following is a list of some of the factors which are thought to influence the permeability either acting collectively or singly: chemical constitution, pore size, electric charge, surface tension, adsorption, hydrogen ion concentration, age and physical condition of tissue, presence of sufficient moisture for solution and ionization of

the lethal material, and temperature.

Consider surface tension alone and the numerous factors which might influence it. The suggestion has been made by Seifriz (7) that a high surface tension would present an interfacial membrane made up of tightly packed molecules between which substances could not pass readily. Low surface tension would mean a loose arrangement of surface molecules and therefore a more permeable membrane.

Hydrogen ion concentration may also be considered. It has been shown that the hydrogen ion concentration both of the cell contents and of the surrounding material has a definite influence on the permeability of that membrane, both to substances passing in and passing out of the cell. Seifriz (7) states that experimental evidence is available which shows that in some cases sodium ions will enter the cell more rapidly in an acid medium than in an alkaline one, and that the speed at which these ions enter increases with a corresponding increase in acidity. Unpublished data by J. H. Pepper and the author show the pH of the regurgitated digestive juices of Mormon crickets to be 4.53 and that these digestive juices are highly buffered both on the acid and alkaline side. In view of these findings it is believed that the permeability of the cells lining the alimentary tract would not vary greatly because of pH changes even though insecticides of strongly acid or basic character are ingested.

Now consider the possible variations in permeability which might be brought about by differences in age and health of the tissue. Since the process of aging is accompanied by a loss in water content of the protoplasm, it is obvious that older tissue containing less water is more

impermeable than that of young tissue. It would then be suspected that in an insect such as the Mormon cricket, the early instars would be much more susceptible to arsenical dusts than the adults. Any abnormality in the functioning of the cells would be expected to influence the permeability of the protoplasmic membrane. It will then be seen that a disturbance of the normal condition due to either sickness or injury would in all probability render the tissue more permeable than that of a healthy individual. Experiments have shown that any abnormal condition of the cell is accompanied by a rapid decrease in electrical resistance with a corresponding increase in permeability.

#### VARIATIONS IN BIOLOGICAL MATERIAL

Keeping in mind the ability of biological material to exhibit variations, exact duplication when using this material should not be expected in experimental procedure. For example, during preliminary investigations in 1937, one lot of crickets collected in the same locality and treated apparently in the same manner as all the other lots, showed 100 per cent mortality at all temperatures in less time than the lowest which appears in Table VIII at 30°C. These variations are as yet largely unexplainable and unpredictable. One may see readily, too, the extreme difficulty of effectively controlling all but a few of the factors mentioned which are thought to influence permeability. With these points in mind, the irregularities in the action of sodium arsenite dusts which are obvious in the following experiments should not be viewed with alarm. Consider the



variations in separate lots of immature crickets as apparent in Table VIII. In the two lots of 1st and 2nd instar insects, it will be noted that at least twice as fast a kill was obtained at all temperatures with the second lot than with the first. Also compare the first lot of 1st and 2nd instars with that of the second lot of 2nd and 3rd instars. It will be noted that in some cases four times as quick a kill was obtained with the latter than with the former.

Temperature changes in a cold blooded animal such as the Mormon cricket, affect a number of the variable factors formerly mentioned, such as surface tension, adsorption, solubility, and ionization. For this reason temperature changes are given particular consideration in this paper even though time may prove them to be less important than some of the other factors.

#### THE ACTION OF DUSTS WHEN APPLIED TO VARIOUS REGIONS OF THE INSECT BODY

Table VII, represented graphically in figure 5, shows the results obtained from studies of the action of sodium arsenite dust when applied to different parts of the body of adult crickets. A 3 to 1 mixture of hydrated lime and C.P. meta sodium arsenite,  $\text{NaAsO}_2$ , was used, and constant temperature and relative humidity were maintained throughout the entire series.

A collar was devised (see figure 6) to prevent the cricket from cleaning any portion of its body, thus preventing any introduction of toxic material into the alimentary tract. In addition, a large protective shield through which the anterior portion of the cricket protruded was provided

TABLE VII.-Per cent mortality for crickets dusted with a 3 to 1 mixture of hydrated lime and sodium arsenite at 36°C. and 50% relative humidity, showing the action of the dust when applied to different parts of the cricket.

Time in hours	Per cent Mortality		
	With collars	Without collars	Tarsi dipped
3	2.5	2.5	0.0
4	11.0	8.0	0.0
5	25.0	20.0	0.0
6	45.0	37.0	10.0
8	81.0	66.0	25.0
10	92.0	85.0	44.0
12	95.0	97.0	58.0
14			71.0
16			78.0
18			84.0
20			87.0

during dusting operations to prevent any direct application of dust to the head and mouth parts. Each cricket was dusted separately with as uniform a coating of dust as was possible and placed in the temperature cabinet. Five lots of twenty each were treated in this manner and the average per cent mortality computed. Undusted check lots both with and without collars showed no mortality in twenty-four hours.

Five lots of twenty each were dusted over their entire body surface and placed in the temperature cabinet along with an equal number whose tarsi only were dipped in the dust.

The crickets whose movements were not hampered by collars began cleaning themselves immediately. No part of their body which could be

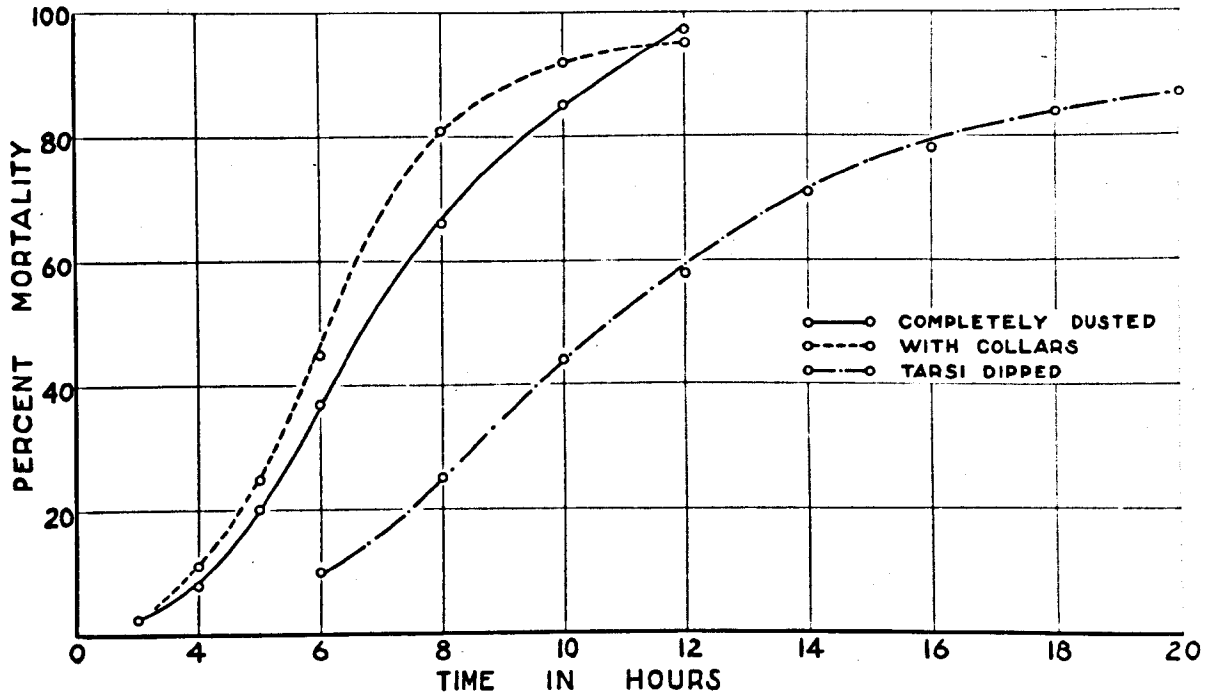


Figure 5. Mortality curves for various methods of applying dusts.



Figure 6. Mormon cricket showing collar attached.

reached was neglected; their antennae, tarsi, legs, ventral side of the abdomen, as well as their ovipositors and claspers were all cleaned. In each of the three types of treatment, the first symptom of effect from the poison was manifest in a general loss of coordination, followed then by a more severe paralysis with considerable regurgitation of digestive juices and deposition of fecal material. Succeeding this stage there appeared to be very little movement except for spasmodic twitchings. The crickets were considered dead in all the following experiments when these spasmodic movements could no longer be induced by gentle prodding.

It will be noted by reference to figure 5 that much the same effect, both in time and percentage kill, was obtained from the dust when it was allowed to act either as a contact poison (collars attached) or as both a contact and stomach poison (no collars attached to prevent ingestion of dust). This indicates that the sodium arsenite dust was effective in either mode of entry. It further indicates that the lethal material could penetrate the intersegmental membranes of the exoskeleton as well as it could the tissue constituting the alimentary canal. By reference to figure 5 it will also be noted that in the case of those crickets whose tarsi only had been dusted, the time for an equal percentage mortality was greatly increased as compared to the other two methods of application of dust. In addition, the ultimate mortality was somewhat lowered. Observations show that the crickets do not all begin cleaning their foot parts immediately after dusting when only the foot parts have been dusted.

On the basis of these findings it is believed that the field practice, whereby dust barriers are laid down in the paths of bands of

crickets should not be expected to be too successful. A short distance travel by the band of crickets over vegetation and earth would in all probability brush off a large portion of the dust which the tarsi had picked up in crossing the dust barrier. There is also the obvious danger to livestock where these heavy concentrations of arsenical dusts are left exposed. When dust barriers are used in connection with furrows wherein the dust is placed in the bottom of these depressions, the case is somewhat different. The insects usually become dusted over a large portion of their body either when entering the furrows or upon leaving it, due to falling down the side walls. The furrow may then be easily filled with earth to eliminate danger to livestock.

Schweis and Burge (6) state that lime and sodium arsenite set up an irritation causing the cricket to attempt cleaning its antennae and foot-parts and that moisture in the atmosphere appears to increase effectiveness of the poison, apparently increasing its irritating quality. Observations have been made by the author on the activity of crickets after they have been dusted with lime and sodium arsenite dust and held under different conditions of temperature and humidity. These observations indicate in general that the crickets begin immediately to clean themselves at temperatures above 20°C. and continue to do so vigorously regardless of humidity conditions. At temperatures under 20°C. they do very little cleaning of dusted parts of their bodies. Observations by the author also indicate that under conditions of high humidity quicker kills are obtained. It is believed that the quicker effects of the dust under conditions of high humidity is not due to an increase in its irritating































