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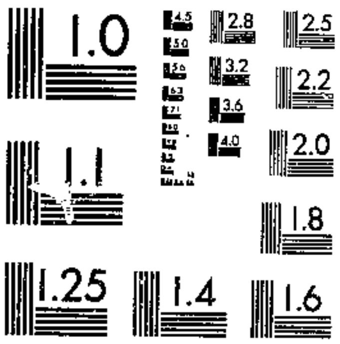

MICROCOPY RESOLUTION TEST CHART
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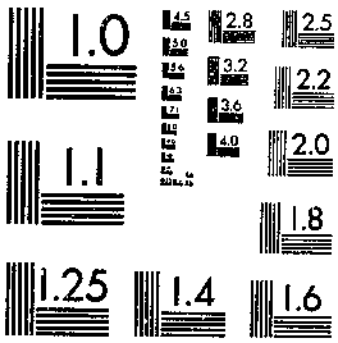

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Evaluation of Baits and Bait Ingredients Used in Grasshopper Control[1]

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CONTENTS

INTRODUCTION

Baiting with poisoned bran mash has long been the most common method of grasshopper control. The poison has generally been some form of arsenic, and molasses and water have usually been added to the mixture. Molasses was first used to make the poison stick to the bran, but later it was believed to be attractive to the hoppers and to keep the bran moist longer than when water was used alone. Many other substances have been tried in an endeavor to increase the attractiveness of the bait, to find cheaper carriers, or to discover a poison that would increase its toxicity or reduce the hazard to man or beast.

[1] Received for publication September 14, 1940. This bulletin does not include any information regarding grasshopper control which may have been obtained since 1938.

[2] The writer expresses appreciation to J. R. Parker for his kindly assistance and the use of his unpublished notes; to F. A. Morton for help and valuable suggestions both in the field and in the laboratory; to A. L. Strand for permission to use unpublished data of the Montana Agricultural Experiment Station; to Stewart Lockwood, under whose direction most of the pan-bait work was done at the Bureau of Entomology and Plant Quarantine laboratory at Billings, Mont.; to F. T. Cowan for his notes taken in Colorado; and finally to all those county agricultural agents, experiment-station superintendents, and farmers without whose aid and cooperation in the use of fields and farm implements very little could have been accomplished.

Much of the published experimental work along these lines has been haphazard or limited because it was not planned to meet the requirements of statistical analysis, and many of the recommendations regarding the use of bait ingredients have been based on insufficient statistical evidence.

In an effort to obtain definite information regarding the value of the various substances suggested for use in poisoned bait, there are assembled in this bulletin all the available experimental data that lend themselves to statistical analysis, both those obtained by the writer and his coworkers over a period of years and published and unpublished results of other investigators. The writer's studies have included an evaluation of experimental methods and other matters relating to the testing and use of poisoned bait as determined by grasshopper surveys and certain farm conditions and cultural practices, as well as methods of mixing and scattering the bait.

HISTORY OF THE USE AND TESTING OF POISONED BAITS

The first mention of the use of poisoned bait was in 1878, when the United States Entomological Commission *(21)* reported several experiments with a mixture of paris green and flour as bait for locusts. Experiments with bran-arsenic mash for the control of grasshoppers in the San Joaquin Valley, Calif., were reported by Coquillet in 1886 *(2)*. Coquillet's mash consisted of bran, arsenic, sugar, and water, the sugar being added to make the arsenic adhere to the flakes of bran. Molasses was soon substituted for the sugar, for Jackson in 1894 *(7)* referred to the successful use, in Colorado, of a bait consisting of bran, paris green, and "some old molasses or other cheap substance to make it stick together." In the same year Bruner *(1)* mentioned the use of bran and arsenic as poisoned bait, but apparently without either sugar or molasses. In 1896 onion growers in New York State *(17)* found a mixture of bran, or middlings, and paris green to be effective against the dark-sided cutworm (*Euxoa messoria* (Harr.)), with a longer period of effectiveness when the bran was moistened.

From the time molasses was first used in grasshopper bait until 1930, experimental work in grasshopper control consisted largely in testing many other substances for their attractiveness in poisoned bait. The substances tried included beet molasses to replace the more expensive cane molasses, common salt, calcium chloride, ground citrus fruits with their juices, lemon and vanilla extracts, geraniol, nitrobenzene, amyl acetate, propyl acetate, butyl acetate, apples, apple flavoring, anise, corn oil, fusel oil, saccharin, sugar, vinegar, stale beer, sawdust, shorts, whey, and fresh horse manure. Studies were also made of different toxic substances to increase the effectiveness of the bait and reduce the hazard to man and beast. The poisons tested were paris green, white arsenic, dry and liquid sodium arsenite, barium fluosilicate, and sodium fluosilicate. Since 1930 greater emphasis has been placed on the value of carriers other than bran. Sawdust, sugar-beet pulp, and cottonseed hulls have been used with some success, and pea bran, oat hulls, and ground alfalfa have been tested but have not proved satisfactory. Mineral oil, replacing water, has been used with bran and other carriers in an attempt to keep the bait soft and palatable over a longer period. Attention has also been paid to the feeding habits and activities of the grasshoppers in relation to local weather and other environmental conditions, for the purpose of determining the most effective time for applying the bait.

At first the mixing was done largely by hand. Since 1934, when control campaigns increased in magnitude, various types of machine mixing have supplanted the slower method to a great extent, and bait spreaders have taken the place of spreading by hand where entire fields have to be covered.

METHODS OF EVALUATING BAITS

Five general methods are used for determining the relative effectiveness of substances suggested for use in poisoned bait—the pan-bait method, the plot-and-cage method, the laboratory-cage method, counts per unit area, and the sweeping method. None of them, of course, is absolutely reliable, but some are more accurate than others.

PAN-BAIT METHOD

The pan-bait method is probably the one most universally employed. Small quantities of several kinds of baits on boards, cards, or piepans are placed on the ground in an infested field (fig. 1), and the hoppers

FIGURE 1.—Pans of bait set out along edge of field. Pan-bait method.

feeding on each bait are counted at regular intervals. This method is based on the assumption that the baits on which the most hoppers are counted are the most attractive. Experience has proved, however, that grasshoppers are rather general feeders and may eat any food material with which they come in contact.

Piepans shellacked and sprinkled with sand before being dried were used by the author and his coworkers as containers. About an ounce of the bait to be tested was scattered over each pan. The grasshoppers were counted every 10 minutes, and temperature, cloudiness, and wind velocity and direction were recorded every half hour during the day. Hoppers have been observed roosting on bait at temperatures as low as 49° F. early in the morning, apparently sunning themselves by standing broadside to the sun's rays. A pan of bait offers a fine roosting place, and a bite now and then may be just incidental, although hoppers attracted to it must be included in the counts as long as there is no way of distinguishing whether the attraction is due to temperature or food. For these reasons the pan-bait method of evaluating baits is unsatisfactory.

Plot-and-Cage Method

The plot-and-cage method has proved to be the best one for determining relative values of different baits. Plots 100 feet square (about one-fourth of an acre) or larger are laid off according to the number of baits to be tested. They are arranged in such manner as to provide approximately the same intensity of infestation and yet be far enough apart to avoid migration from one plot to another. The size and shape of the plots may be made to conform with the distribution of the hoppers, such as oblong plots for fence-row infestations and square plots for open-field infestations.

The bran mash is scattered over the entire plot at the standard rate of 10 pounds (dry weight) to the acre. The baits are usually scattered in the morning as soon as the air temperature has reached 68° F., over as many plots as the operator can cover in about an hour. If much more time is used, there is danger of getting the mash to the grasshoppers on some plots too long before or after optimum feeding temperatures are reached. The time of application in North Dakota, South Dakota, and Montana is usually between 6 and 9 a. m., depending principally on the time of year.

Grasshoppers are collected 3 hours later, when they have had an opportunity to feed on the poisoned bait while it is still fresh during the optimum feeding period, but before they have become so sluggish from the effects of the poison that they are missed in sweeping. This 3-hour interval between application of the mash and collection of hoppers must be observed carefully for each plot, because any variation will cause an error in the results. Check collections are made simultaneously from unbaited areas for the purpose of determining the mortality due to handling and natural causes.

Time of day and conditions of air temperature, cloudiness, and wind should be recorded when the baits are scattered and every half hour thereafter until collections are finished, to provide a check on the probable period of feeding before the grasshoppers are caught and caged.

Each plot is divided into quarters and provided with two cages. Collections are made from the center of each quarter, and grasshoppers from opposite quarters are placed in the same cage. A special net (fig. 2) is used which tapers to a cylindrical extension at the bottom, of the right size to hold a 1-quart ice-cream carton, which is kept in place by a rubber band around the outside of the net near the top of the carton. This type of net was first used by Cowan in Colorado (*3*). With the lid off the carton, the net is trailed over the plot at a brisk walk or dogtrot. When sufficient hoppers have been collected, the carton is removed from the net and the lid replaced. Four cartons, one for each quarter, bearing the plot number, are used for each plot. After all the collections have been made, the cartons are taken to a shed or shelter, and the hoppers are placed in the cages bearing the proper plot numbers, where they are given fresh green food daily.

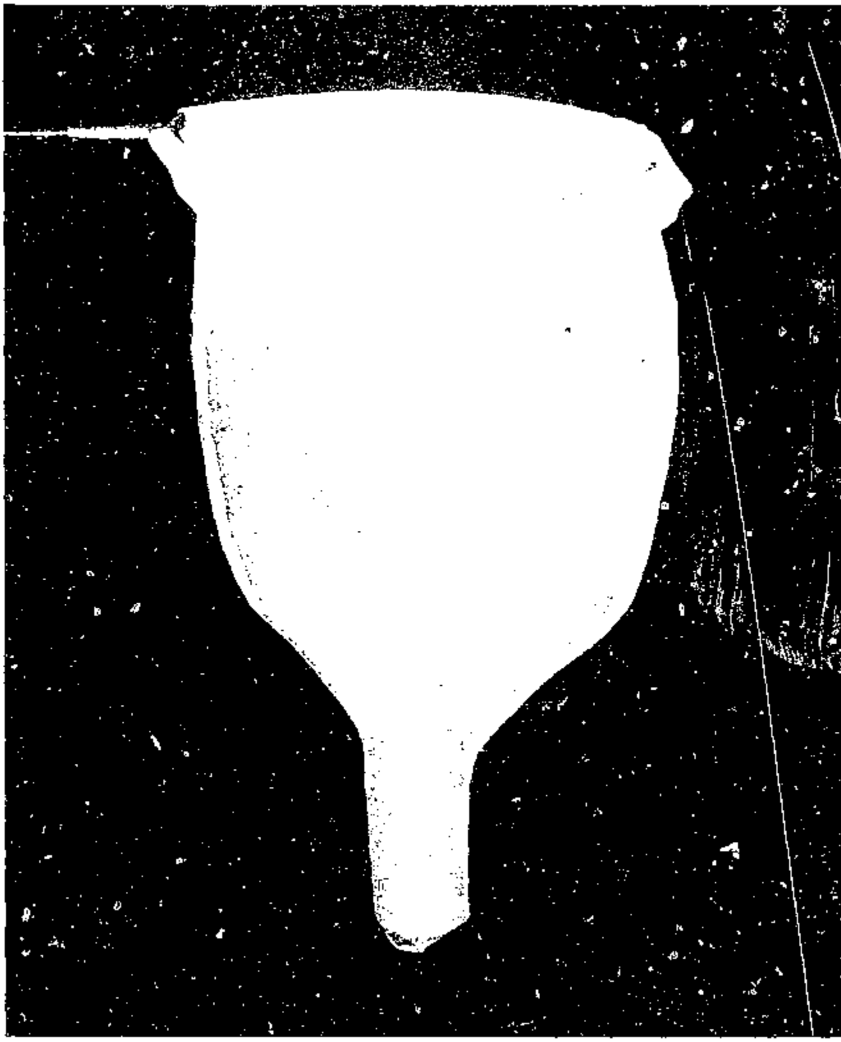

FIGURE 2.—Type of [illegible] ice-cream carton used for collecting grasshoppers in plot or large experiment.

At first the cages were set up in the field on the plots and the hoppers were collected and caged directly from the nets, but this practice was discontinued on account of frequent destruction of cages by wind or hail before completion of the experiment. Collection in cartons makes it possible to have the cages located in a shelter at a distance from the plots.

The cages vary in size from 1 to 1½ cubic feet and are made of dressed 1-inch lumber, resawed in 1- to 1½-inch strips and resawed again the narrow way in order that the edges of the screen can be cleated between. The screen is 20-mesh galvanized wire. A solid wooden bottom is used and made in such a way as to prevent warping (fig. 3). The top can be either solid or hinged. When solid, the opening of the cage is in the lower half of one side in the form of a drop door. When the top is hinged, it is hinged in the middle, one part

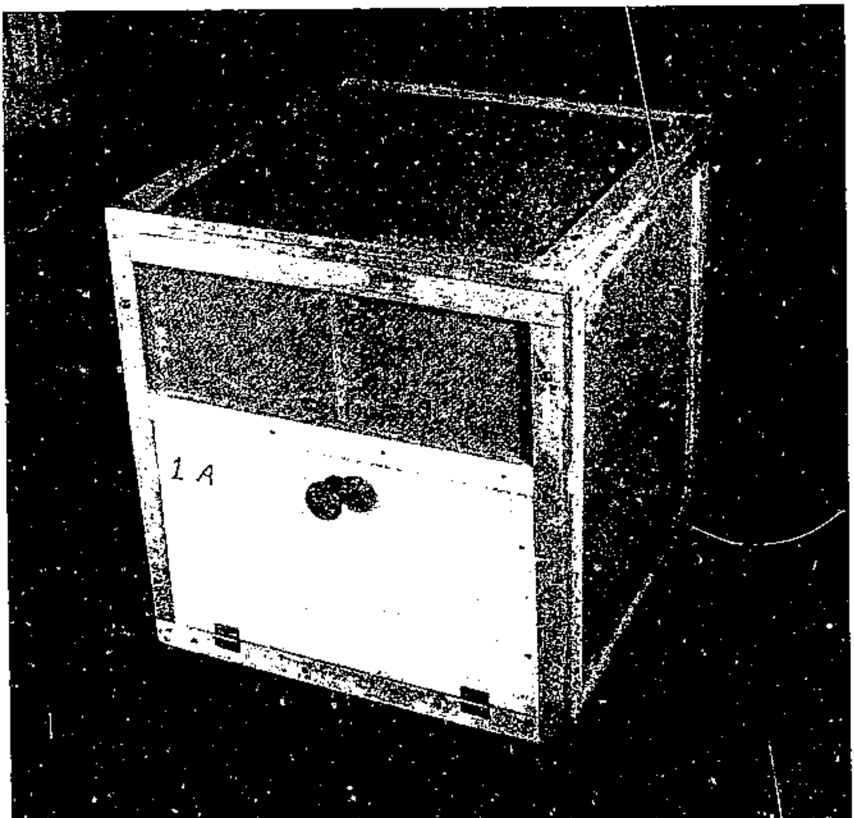

FIGURE 3.—Wire-screen cage used in both plot-and-cage and laboratory-cage experiments.

being solid to the frame and the other forming a lid, to prevent the escape of the specimens during manipulation.

The dead grasshoppers are counted and removed from the cages every day for 3 days following that on which the plots were poisoned, and the living hoppers left on the last day are also recorded. From these counts the mortalities on the plots represented by the different cages are calculated. Since some feeding on the baits continues far beyond the 3-hour time at which the samples are taken, these figures cannot be considered as representing the total mortality for any particular kind of bait, but they show relative values for the various formulas, give a fair idea of their effectiveness, and can be analyzed statistically.

The standard error of the total mortalities of the caged hoppers due to the various baits and tests is large on the first day but falls off greatly the second day, and counts on succeeding days have shown that the total mortality is more or less stable thereafter. This would indicate that the relative mortalities remain about the same after the second day, and that 3-day counts therefore give practically as good an idea of the comparative efficiency of the various baits as can be obtained over a longer period.

LABORATORY-CAGE METHOD

In an effort to advance the study of poisoned baits as rapidly as possible, a method of studying the relative effectiveness of various baits was devised for laboratory use so that many new substances could be given preliminary trials during the long winter period. Substances showing promise could then be given more accurate and complete tests in the field during the short summer period of only about 6 weeks when tests can be made before too much migration upsets results. All the laboratory-cage tests reported in this bulletin were conducted at the Bozeman, Mont., laboratory of the Bureau of Entomology and Plant Quarantine.

From 50 to 100 young hoppers per cage are placed in 1-cubic-foot wire-screen cages such as are used in the plot-and-cage experiments (fig. 3). They are taken from stock cages containing hoppers hatched from eggs collected in the fields. The hoppers are counted as they are drawn one at a time into a glass tube by means of a motor-driven suction pump.[3] This tube is 1½ inches in diameter and 8 inches long, and is connected by rubber tubing to the pump and to a nozzle made of ½-inch glass or rubber tubing. The lot is then emptied into the bait-test cage. Many individuals can be handled in a short time with this apparatus. Glass vials containing sprouted wheat in water are placed in the cages and replenished daily to keep green food available to the hoppers at all times. One-fifth gram (dry weight) of bait, the equivalent of 20 pounds per acre, is scattered over the floor in each cage. This may seem to be a heavy dosage, but it must be remembered that there are 50 to 100 hoppers per square foot of floor in the cage, whereas 25 to 50 per square foot in the field is a heavy infestation for which a minimum of 10 pounds per acre is ordinarily recommended. The dead hoppers in the cages are counted and recorded as in the plot-and-cage method.

The laboratory-cage method does not give the conclusive evidence furnished by the field tests, because the hoppers are forced into closer contact with the baits and outside weather conditions are eliminated. It does indicate, however, those baits that show promise and eliminates those that are obviously useless.

COUNTS PER UNIT AREA

Field tests in which the number of dead hoppers per unit area or decreases in population of live hoppers are recorded do not give an accurate idea as to the relative effectiveness of the baits, although many opinions are based on such data. Continued hatching and local movements of grasshoppers may cause changes in population,

[3] This apparatus was devised by F. A. Morton, of the Bozeman, Mont., laboratory.

and such important factors as mixing, scattering, and time of application of the baits must also be taken into consideration.

Counts of live hoppers per unit area are sometimes obtained by dropping a cage over them in the field and then gassing the hoppers that are caught. This method is unsatisfactory because many individuals may escape by flight or on foot where the cage does not make contact with the ground owing to unevenness of the surface or heavy vegetation.

Sweeping Method

Since the plot-and-cage method does not give an accurate account of the change in population on a plot after an application of the bait, an effort was made, during the summer of 1933 at Dickinson, N. Dak., to devise a method for observing differences in population over a period of several days after application. Plots of from one to several acres were used. A net was held close to the ground with the bow in a vertical position, and five quick steps were taken, the net being trailed and then brought up quickly to cage all the hoppers collected. The number caught in the net was then recorded. Sweeps were made at five places along a diagonal line across each plot. Collections were made before poisoning and, beginning 24 hours later, on 5 successive days under as nearly as possible the same conditions of time and weather. To serve as checks similar sweepings were made on unpoisoned plots.

Only gross differences in population are measurable by this method, but it is believed that more accurate data are obtained in this way than by mere visual estimates of populations. Some interesting facts brought out by this study will be discussed in the section Difficulty in Appraisal of Results Because of Population Changes.

In Colorado and elsewhere populations have been estimated by counting the hoppers collected in 50 sweeps of a net before poisoning a field and for several days thereafter. The main objection to this method is the variation in the sweeping act itself and in the agility of the hoppers from day to day.

STATISTICAL METHODS FOR ANALYZING DATA

All the data derived from pan-bait, plot-and-cage, and laboratory-cage tests have been brought together and analyzed according to accepted statistical methods. In the pan-bait tests effectiveness is indicated by the number of grasshoppers per day coming to each bait, in the other tests by the percentage of mortality obtained for each bait.

When only two kinds of baits were compared, the standard error of the mean difference was used to test the significance of the difference. The standard error was obtained from the following formula ("Student's" pairing method):

$$S_{\bar{D}}=\sqrt{\frac{\Sigma D^2-n\bar{D}^2}{n(n-1)}}$$

where $S_{\bar{D}}$ is the standard error of the mean difference, D is the difference of a single pair, $\bar{D}$ is the mean difference, and n is the number of tests.

When several kinds of bait were compared in the same replicated tests, the generalized standard error for any bait was used from the following formula ("Student's" variance method) (*18*):

$$S=\sqrt{\frac{MN(Q\ (T^2)-Q\ (R^2)-Q\ (G^2))}{(M-1)\ (N-1)}}\Bigg/\sqrt{N}$$

where M is the number of baits, N is the number of replications, T is the individual test, R is the mean of mortality percentages or of the numbers feeding on a given bait, and G is the mean of each replication, whether mortality percentage or number feeding.[4] Likewise

$Q\ (T^2)$ equals $\frac{\Sigma T^2}{MN}-\overline{X}^2$ (in which $\overline{X}$ is the general mean of all tests),

$Q\ (R^2)$ equals $\frac{\Sigma R^2}{M}-\overline{X}^2$, and $Q\ (G^2)$ equals $\frac{\Sigma G^2}{N}-\overline{X}^2$.

The standard error of the difference between any two baits was obtained as follows:

$$S_{\overline{D}}=\sqrt{S^2+S^2}=S\sqrt{2}.$$

The experimental data have been tabulated in the order of the effectiveness of the bait and the significant differences shown. Generally a difference, to be significant (odds of 19 to 1) must be approximately twice the standard error, although this does not mean that a true difference less than twice the standard error does not exist. A more accurate statement would be that, if the difference between two baits is not twice the standard error, we cannot be certain that a real difference exists. The finding of any difference is evidence that it exists in that particular experiment.

BAIT MATERIALS

Twenty-six substances used experimentally as attractants, six used as toxic ingredients, and various carriers in dry, wet, and oiled bran have been evaluated as to their use in poisoned bait according to the statistical method already explained.[5]

ATTRACTANTS

MOLASSES

A summary of all the pan-bait tests in which cane-molasses baits were compared directly with baits containing no molasses is presented in table 1. In an average of 94 tests conducted by the writer the difference in results between the two types of baits was not significant. Of these tests, 55 show molasses to be better, 2 show the two baits to be of equal value, and 37 show baits without molasses to be better. In the results of other investigators molasses was significantly better

[4] This formula gives the same results as those given by the more widely and recently used formulas for the analysis of variance.

[5] In the evaluation of the data of other investigators use was made, not only of published data, but also of the original notes and other material that the observer did not publish. In the tables included in this bulletin all data not tied up with a literature reference are taken from unpublished reports.

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in 3 cases (i. e., the differences were greater than zero), there was no significant difference in 2 cases, and baits without molasses were better in 1 case. Morrill (*8*), in 4 tests in Arizona in 1918, found that baits without molasses were as effective as baits with molasses. In pan-bait and plot-and-cage experiments carried on by the writer in Montana, South Dakota, and Minnesota (tables 2 and 17) and in laboratory-cage tests at Bozeman, Mont., (table 3) no significant differences were found between poisoned baits that contained cane molasses and those that did not.

TABLE 1.—*Comparison of attractiveness of baits with and without cane molasses in in pan-bait tests by various investigators, 1921–27*

Investigators	State	Year	Tests	Average number of grasshoppers feeding on bait: With molasses	Average number of grasshoppers feeding on bait: Without molasses	Average number of grasshoppers feeding on bait: Difference	Difference divided by error
			Number	*Number*	*Number*	*Number*	
Shotwell, average of all experiments			94	190	167	23±14.67	1.57
Swenk (*19*), and Swenk and Wehr (*20*).	Nebraska	1923, 1927	22	104.6	112.7	−8.1±17.13	.47
Ford and Larrimer (*4, 5*)	Indiana	1921	6	553.1	394.8	158.3±78.28	2.02
			17	471.4	441.2	30.2±20.98	1.44
Painter, Fluke, and Granovsky (*9*).	Wisconsin	1923, 1924	14	444.4	319.3	125.1±66.54	1.88
Parker (*11*)	Minnesota	1923	30	220.0	196.0	24±8.34	2.88
Parker	Montana	1924	34	113.6	159.4	−45.8±17.18	2.67

TABLE 2.—*Comparative effectiveness of cane and beet molasses and amyl acetate in varying combinations in poisoned bran baits, in plot-and-cage tests by Shotwell in various localities, 1926 and 1932* [1]

Montana, 1926 (16 replicates): Poison and quantity	Attractant	Mortality	South Dakota, 1932 (12 replicates): Poison and quantity	Attractant	Mortality
		Pct.			*Pct.*
Sodium arsenite (liquid, 8-pound material) 1 quart	Cane molasses	92.2	Sodium arsenite (dry) 2½ pounds	Cane molasses and amyl acetate	66.5
	No molasses	88.1		Cane molasses	59.9
	Beet molasses	86.3		None	57.4
Check, no bait		10.2	Sodium fluosilicate 5 pounds	Cane molasses	56.0
Minimum significant difference		6	Check, no bait		4.5
			Minimum significant difference		9.5

[1] All quantities are per 100 pounds of bran.

TABLE 2.—*Comparative effectiveness of cane and beet molasses and amyl acetate in varying combinations in poisoned bran baits, in plot-and-cage tests by Shotwell in various localities, 1926 and 1932*—Continued

Minnesota, 1932, experiment 1 (5 replicates)

Poison and quantity	Attractant and quantity	Mortality
		Pct.
Bag-house arsenic 5 pounds.	Cane molasses 1½ gallons.	86.5
	Amyl acetate 6 ounces	85.4
	Cane molasses 1½ gallons, amyl acetate 3 ounces.	82.1
	Beet molasses 1½ gallons, amyl acetate 3 ounces.	80.7
	Beet molasses 1½ gallons.	79.8
	Wet bran	76.1
Check, no bait		38.2
Minimum significant difference.		12

Minnesota, 1932, experiment 2 (5 replicates)

Poison and quantity	Attractant and quantity	Mortality
		Pct.
Crude arsenic 5 pounds.	Beet molasses 1½ gallons, amyl acetate 3 ounces.	94.0
	Cane molasses 1½ gallons, amyl acetate 3 ounces.	90.3
Sodium fluosilicate 5 pounds.	Beet molasses 1½ gallons, amyl acetate 3 ounces.	89.1
	Beet molasses 1½ gallons.	80.0
Check, no bait		47.3
Minimum significant difference.		10

TABLE 3.—*Relative effectiveness of sodium arsenite and fluosilicate baits, with and and without molasses (or sugar solution) and amyl acetate or combinations of these attractants, in laboratory-cage tests by Shotwell, Montana, 1933* [1]

Experiment 1 (5 replicates)

Poison (quantities in pounds)	Attractant and quantity	Mortality
		Pct.
Sodium arsenite (dry) 2½.	Beet molasses 2 gallons, amyl acetate 3 ounces.	75.6
	Cane molasses 2 gallons, amyl acetate 3 ounces.	72.4
Sodium fluosilicate 5.	None	72.4
Sodium arsenite 2½	Cane molasses 2 gallons.	70.0
	Amyl acetate 3 ounces.	68.6
	Beet molasses 2 gallons.	67.5
Sodium fluosilicate 2½.	None	59.4
Sodium arsenite 2½	None	57.7
Sodium fluosilicate 2½.	Cane molasses 2 gallons, amyl acetate 3 ounces.	15.1
Sodium fluosilicate 5.	Cane molasses 2 gallons, amyl acetate 3 ounces.	15.1
Check, no bait		6.7
Minimum significant difference.		14

Experiment 2 (5 replicates)

Poison (quantities in pounds)	Attractant and quantity	Mortality
		Pct.
Sodium fluosilicate 4.	Sugar solution (saturated) 2 gallons.	90.7
	Amyl acetate 3 ounces	78.4
Barium fluosilicate 4.	Amyl acetate 3 ounces	72.5
Sodium fluosilicate 4.	None	71.5
Barium fluosilicate 4.	None	70.3
	Cane molasses 2 gallons, amyl acetate 3 ounces.	68.1
	Cane molasses 2 gallons.	64.5
Sodium fluosilicate 4.	Cane molasses 2 gallons.	62.8
	Cane molasses 2 gallons, amyl acetate 3 ounces.	61.8
Sodium arsenite (dry) 2½.	Cane molasses 2 gallons.	58.9
	Amyl acetate 3 ounces	57.1
Check, no bait		0.2
Minimum significant difference.		17.3

[1] All quantities are per 100 pounds of bran.

In an average of 44 pan-bait tests (table 4) in which baits flavored with cane molasses were compared with those flavored with amyl acetate, there was no significant difference in attractiveness. The average number of grasshoppers feeding on the cane-molasses bait was 196 and on the amyl acetate bait 188, with a difference of 8, whereas to be significant the difference should be 24. Neither did the amyl acetate combined with molasses add to the attractiveness.

TABLE 4.—*Relative attractiveness of baits containing cane and beet molasses, amyl acetate, lemons, and salt, in various combinations,*[1] *in pan-bait tests by various investigators, Wisconsin and Montana, 1922–25*

Parker, Montana, 1922 (*10*)	
Attractant and quantity	Grasshoppers feeding
	No.
Experiment 1 (6 replicates):	
Amyl acetate	179
Salt	137
Molasses	128
Lemons	121
Minimum significant difference	52
Experiment 2 (4 replicates):	
Amyl acetate 4 ounces, molasses, salt	240
Amyl acetate 2 ounces, molasses, salt	244
Amyl acetate 4 ounces, salt	231
Amyl acetate 2 ounces, salt	215
Salt, lemons, molasses	205
Salt	196
Amyl acetate 4 ounces, molasses	153
Amyl acetate, salt	130
Minimum significant difference	59
Experiment 3 (7 replicates):	
Amyl acetate, molasses, salt	78.4
Amyl acetate, salt	55.5
Lemons, molasses, salt	54.5
Salt	52.4
Minimum significant difference	12.5

Painter and Granovsky, Wisconsin, 1923 (6 replicates)	
Attractant	Grasshoppers feeding
	No.
Amyl acetate, molasses	962.5
Molasses	931.8
Amyl acetate	841.7
Salt	763.2
Amyl acetate, molasses, salt	704.7
Check, no attractant	658.2
Minimum significant difference	237

Shotwell, Montana, 1924, 1925 (40 replicates)	
Attractant	Grasshoppers feeding
	No.
Cane molasses	112
Cane molasses, amyl acetate	101
Beet molasses	90
Check, no attractant	87
Beet molasses, amyl acetate	84
Minimum significant difference	13

Lockwood and Shotwell, Montana, 1925 (32 replicates)	
Attractant and quantity	Grasshoppers feeding
	No.
Fresh baits:	
Cane molasses, amyl acetate	71
Cane molasses	71
Amyl acetate	67
Cane molasses, lemons	65
Lemons	65
Beet molasses	64
Beet molasses, lemons	63
Beet molasses, amyl acetate	62
Check, no attractant	62
Day-old (fermented) baits:	
Beet molasses, lemons	38
Cane molasses, amyl acetate	37
Cane molasses, lemons	37
Beet molasses, amyl acetate	33
Minimum significant difference	10.3

[1] Quantities are per 100 pounds of bran. Where not specified the quantity of amyl acetate was 3 ounces, of molasses 2 gallons, of lemons 1 dozen, and of salt 4 pounds.

In the pan-bait tests with cane and beet molasses and amyl acetate (tables 4 and 5) cane molasses was better than the check or beet molasses. However, in the plot-and-cage tests (table 2) and the laboratory-cage tests (table 3) neither cane nor beet molasses seemed to increase the attractiveness of the mash over the bait without molasses.

Where cane molasses was compared with lemons (table 4), there was no significant difference between the two. In 38 pan-bait tests an average of 80.0 grasshoppers fed on the molasses and 73.8 on the lemons. The minimum significant difference was computed to be 8 grasshoppers.

TABLE 5.—*Effect of varying quantities of cane and beet molasses and amyl acetate, alone and in combination, on attractiveness of baits,*[1] *in pan-bait tests by Lockwood, Montana, 1924*

Experiment 1 (4 replicates)			Experiment 2 (4 replicates)		
Kind of molasses and quantity in gallons	Amyl acetate	Grass-hoppers feeding	Kind of molasses and quantity in gallons	Amyl acetate	Grass-hoppers feeding
	Ounces	*Number*		*Ounces*	*Number*
Cane 4	0	298	Cane 4	0	295
Cane 2	0	258	Cane 2	0	288
Cane 2	2	252	Cane 4	4	268
Cane 4	2	234	Cane 4	3	260
None	2	226	Cane 0	3	228
Beet 2	2	219	Cane 2	3	223
Cane 2	3	219	Cane 0	4	218
Cane 4	3	217	Cane 2	4	214
None	3	210	None (wet bran)	0	202
Beet 2	0	190	Beet 2	0	199
Beet 4	3	183	Beet 2	3	180
Beet 2	3	167	Beet 2	4	162
None (wet bran)	0	167	Beet 4	3	139
Beet 4	0	159	Beet 4	0	137
Beet 4	2	158	Beet 4	4	121
Minimum significant difference		81	Minimum significant difference		68

[1] Quantities are per 100 pounds of bran.

In 13 plot-and-cage tests in North Dakota in 1933 (table 24) the mortality with a bait containing cane molasses and sodium arsenite was only 1 percent higher than with a bait containing sodium arsenite alone. This was not significant.

On the basis of all the pan-bait experiments (table 1) the chances are about 3 out of 5 that the cane molasses will increase the attractiveness of the bait, and then only 5 to 10 percent at the most.

Regarding beet molasses little experimental work has been recorded in the literature other than that by Cowan (*3*) in Colorado. In plot-and-cage tests Cowan found no significant difference between cane and beet molasses (table 11). In one set of tests cane molasses was better than wet bran only, but in the other there was no significant difference. Between the beet molasses and wet bran only, the difference was not significant in either of his experiments. The addition of either amyl acetate or salt did not improve the attractiveness of the bait. In 40 tests by the pan-bait method (table 4) Shotwell found beet molasses to be less attractive than cane molasses and not significantly different from the check. In two sets of tests in which he used 2 and 4 gallons of beet or cane molasses alone and in various combinations with amyl acetate (table 5) Lockwood found practically all the baits with beet molasses significantly less attractive than those with cane molasses. The beet molasses was no better than the check, and when used at the rate of 4 gallons per 100 pounds of dry bran it even acted as a repellent.

In plot-and-cage tests in Montana in 1926 (table 2), where sodium arsenite baits containing cane or beet molasses were compared with similar baits with no molasses, the mortality with the beet molasses was 5.9 percent less than with the cane molasses and 1.8 percent less than with no molasses. In later work in Minnesota (table 2) the addition of amyl acetate seemed to make beet-molasses bait equal to cane-molasses bait.

The experiments show that cane molasses is considerably more effective than beet molasses. The beet molasses has never proved to be of any value. The results with both types, however, were so variable as to give no grounds for the use of either in poisoned bait.

The original object in using molasses was to make the poison stick to the bran, and in the feed-milling process of mixing the bran and arsenic it is needed for this purpose. The idea has arisen, however, that molasses is an attractant and, in spite of experimental evidence, it is hard to convince people that this is not so. The satisfactory results obtained in recent Federal grasshopper-control campaigns where no molasses was used have confirmed the experimental data.

AMYL ACETATE AND CITRUS FRUITS

Amyl acetate was first suggested for use in poisoned bait by R. A. Cooley in 1918, and tested by Parker and Seamans (table 13). Their conclusion that amyl acetate was better than other attractants was based on the results of 3 days' experiments by the pan-bait method. In 1920–21 Parker carried on in Montana three pan-bait experiments comparing various combinations of amyl acetate, cane molasses, and salt (table 4), but in only one did he find a significant difference in favor of the amyl acetate; and in two other experiments conducted in 1923 in Minnesota (table 13) he found no significant difference between amyl acetate and some other substances. No check composed of wet bran alone was used in any of these tests.

In pan tests conducted in Montana in 1924 (table 6) Parker found no significant difference between bait containing bran and amyl acetate and that containing wet bran alone. In work done in Wisconsin by Painter, Fluke, and Granovsky (table 6) there was no significant difference between the amyl acetate and the check. Swenk in Nebraska (table 6) found no significant differences between various quantities of amyl acetate ranging from the equivalent of 1 to 24 ounces per 100 pounds of bran. In 75 tests in Montana, Lockwood and Shotwell showed the amyl acetate to have some value (table 6). In an average of 114 tests by various investigators (table 6) there was a difference over the check of bran and water that was barely significant. However, in 76 of these cases the amyl acetate was more attractive than the check, in 35 cases the check was better, and in 3 cases there was no difference.

In two pan-bait experiments by the writer in South Dakota the addition of amyl acetate to a bait containing sodium arsenite, bran, and water did not give a significant increase in its attractiveness (table 17).

The pan-bait observations indicate that the addition of amyl acetate may result in an average increase of 6 or 7 percent in the attractiveness of the bait about two out of three times.

None of the plot-and-cage and laboratory-cage experiments (tables 2 and 3) conducted by the writer showed any advantage in using amyl acetate in addition to bran, water, and the toxicant. Cowan, in two experiments carried out in Colorado (table 11), found amyl acetate to be of no value.

Table 6.—*Relative attractiveness of baits containing varying amounts of amyl acetate in pan-bait experiments by several investigators, 1923–24*

Investigators	State	Year	Replicates	Grasshoppers feeding on bait containing amyl acetate in indicated amounts																Minimum significant difference
				0 (check)	1 ounce	2 ounces	3 ounces	4 ounces	5 ounces	6 ounces	8 ounces	10 ounces	12 ounces	14 ounces	16 ounces	18 ounces	20 ounces	22 ounces	24 ounces	
			No.	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	
Swenk (*19*)	Nebraska	1923	12	......	165	177	201	177	......	204	198	182	176	172	192	192	147	153	152	87
Painter, Fluke, and Granovsky	Wisconsin	1923–24	4	1,063	819	911	901	877	......	......	1,053	......	1,040	......	983	......	......	......	......	256
Lockwood	Montana	1924	4	227	......	221	284	304	255	......	......	......	......	......	......	......	......	......	......	70
Parker	do	1924	18	148	......	......	155	......	......	......	......	......	......	......	......	......	......	......	......	12.4
Lockwood and Shotwell (summary)	do	1924–25	75	110	......	......	122	......	......	......	......	......	......	......	......	......	......	......	......	7.8
Painter, Fluke, and Granovsky (summary).	Wisconsin	1923–24	21	752	......	......	798	......	......	......	......	......	......	......	......	......	......	......	......	110
Summary of last three experiments.	......	......	114	234	......	......	252	......	......	......	......	......	......	......	......	......	......	......	......	18

Amyl acetate was employed to replace lemons, which had been advocated for use in the poisoned bait. In 101 pan tests in which a direct comparison was made (table 7), the average difference in attractiveness between these two was not significant. Of these tests 57 showed amyl acetate to be more attractive to the grasshoppers, 43 showed the lemons to be more attractive, and 1 showed the two materials to be equally attractive. Experiments by Swenk and Wehr (tables 7 and 14) and Painter, Fluke, and Granovsky (table 7), as well as by the writer (table 4), gave similar results. Parker found, in work done in Montana (table 4) and Minnesota (table 13), that amyl acetate was significantly better than lemons.

TABLE 7.—*Comparison of amyl acetate and lemons as attractants in baits in pan-bait tests by several investigators*

Investigators	State	Year	Tests	Grasshoppers feeding on bait containing—			Minimum significant difference
				Amyl acetate 3 ounces[1]	Lemons 1 dozen[1]	No attractants (check)	
			Number	*Number*	*Number*	*Number*	*Number*
Swenk and Wehr (*20*)	Nebraska	1923	30	201.2	196.1		24
Painter, Fluke, and Granovsky	Wisconsin	1923-24	8	923.3	1,029.7	862.0	153
Average of six experiments by several investigators.			101	205	199		14

[1] Quantities are per 100 pounds of bran and 10 to 12 gallons of water.

Since amyl acetate seems to be equally as attractive as lemons, and is cheaper, it should replace them if they are of any value in the bait.

Both lemons and oranges were formerly advocated and used in baits, but their use has been discontinued as too expensive. In 45 pan-bait tests by the writer (table 8) the same number of grasshoppers fed on bait containing ground lemons as on bait without lemons. A summary of 53 tests (table 8) shows a slightly significant difference between baits containing lemons and the check. In 29 instances lemon baits were better than baits without lemons, in 23 the bait with no lemons was better, and in 1 they were equal. Examination of all the tables dealing with lemons and oranges shows that their use in poisoned bran mash is not necessary.

TABLE 8.—*Comparison of attractiveness of baits containing lemons with baits not containing lemons in a summary of all tests by the pan-bait method, Montana, 1924–25*

Investigators	Tests	Grasshoppers feeding on bait		
		With lemons	Without lemons	Difference
	Number	*Number*	*Number*	*Number*
Lockwood, Shotwell, average of all experiments	45	65	65	0
Average of all reported experiments	53	211	185	26±12.66

SODIUM AND CALCIUM CHLORIDES

The use of sodium chloride (common salt) arose from frequent observations that grasshoppers would gnaw fork and hoe handles and eat the armpits out of shirts, presumably in their desire for salt.

In Montana Parker (table 9) and Lockwood and Shotwell (tables 9 and 10) found that calcium or sodium chloride, instead of increasing the attractiveness of the bait, usually acted as a repellent. In Wisconsin Painter, Fluke, and Granovsky and in Minnesota Parker found that sodium chloride did add to the attractiveness, and Ford and Larrimer in Indiana and Swenk and Wehr in Nebraska found that it either acted as a repellent or had no appreciable effect (table 9). Swenk found no significant difference between bait with calcium chloride and that without (table 9). These results might indicate that in areas of alkaline soil salt does not add to the attractiveness of the bait and in areas of less alkalinity it may help. However, as a general rule salt should not be used in the Northwestern States.

TABLE 9.—*Relative attractiveness of baits containing sodium chloride, calcium chloride, and without either salt in pan-bait tests by several investigators, 1921–25*

Investigator	State	Year	Tests	Grasshoppers feeding on bait containing— Sodium chloride [1]	Calcium chloride [1]	Check (without either salt)	Difference between sodium chloride and check	Difference divided by error	Difference between sodium chloride and calcium chloride	Difference between calcium chloride and check
			No.	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*
Parker	Montana	1924	34	74.3		152.6	−78.3±20.68	3.79	------	------
Lockwood, Shotwell, average of all experiments.	do	1924–25	35	90	87	102	−12±8.64	1.39	3±8.64	−15±8.64
Painter, Fluke, and Granovsky, average of all experiments.	Wisconsin	1923–24	15	351.1		298.7	52.4±17.53	2.99	------	------
Ford and Larrimer, average of all experiments.	Indiana	1921	5	230.2		303.2	−73±30.32	2.41	------	------
Parker *(11)*	Minnesota	1923	25	59		50	9±3.73	2.41	------	------
Swenk and Wehr *(20)*	Nebraska	1923	18	206.0		223.3	−17.3±18.64	.93	------	------
Swenk *(19)*	do	1923	20	------	49.8	40.9	------		------	8.0±6.09

[1] 5 pounds per 100 pounds of bran in Lockwood and Shotwell experiments, 4 pounds in others

TABLE 10.—*Relative attractiveness of varying amounts of sodium and calcium chlorides in pan-bait tests (3 replicates) by Lockwood, Montana, 1924*

Salt	Quantity	Grasshoppers feeding	Salt	Quantity	Grasshoppers feeding
	Pounds	*Number*		*Pounds*	*Number*
Check, none	0	493	Calcium chloride	4	402
Sodium chloride	4	426		5	347
	5	324		6	378
	6	337		7	385
	7	326	Minimum significant difference.	------	127

If the farmers had attributed the roughening of their pitchfork or hoe handles by grasshoppers to the hoppers' desire for the increased moisture in the sweaty handles instead of for the salt, there might have been a different story regarding the use of salt in poisoned bait.

COMPARISON OF FERMENTED AND UNFERMENTED BAITS

Swenk (*19*) used various fermented and unfermented baits in 36 pan-bait tests. His results showed the unfermented baits to be somewhat better than the fermented baits, but not significantly so. The average number of grasshoppers feeding on the unfermented bait was 52.7, on the fermented bait 43.6, making a difference of 9.1, whereas the minimum significant difference would be 10. In some of their tests with lemons and amyl acetate, Lockwood and Shotwell compared fresh baits with baits that had stood for 1 day before being spread, and found the day-old baits to be significantly less attractive (table 4).

SAWDUST-WHEY BAITS

In the 1934 grasshopper campaign in Wisconsin 8,500 tons of a sawdust-whey bait were used successfully. The formula was sawdust 1 bushel, whey 1 gallon, white arsenic 1 pound or liquid sodium arsenite 1 pint, and water ½ gallon; and the bait was spread at the rate of 20 pounds per acre. There appear to be no published experimental data supporting the use of whey, and H. F. Wilson, of the University of Wisconsin, states that in comparative tests bran-molasses baits appeared to be better than the baits containing whey. However, since whey is much cheaper than molasses, and good results have followed the use of sawdust-whey bait, Wisconsin authorities prefer to use it if only because the farmers have confidence that it attracts the grasshoppers.

MISCELLANEOUS ATTRACTANTS

In tables 11 to 15, inclusive, are tests of several other substances as attractants in poisoned bait. None of these materials proved of sufficient importance to be seriously considered. In some localities farmers sometimes mix ground onion with the bait, but there appear to be no experimental data supporting its use. In six pan-bait tests with paris green, lemons, and molasses Swenk and Wehr found no significant difference when soap was added to the bait (table 14).

TABLE 11.—*Effect of adding various attractants to poisoned baits in plot-and-cage tests by Cowan (3), Colorado, 1931 and 1932*

Experiment 1, 1931 (12 replicates): Attractant and quantity [1]	Mortality	Experiment 2, 1932 (12 replicates): Attractant and quantity [1]	Mortality
	Percent		*Percent*
Beet molasses 2 gallons, amyl acetate 3 ounces	68.4	Beet molasses 2 gallons	52.9
Cane molasses 2 gallons	68.2	Cane molasses 2 gallons	52.3
Beet molasses 2 gallons	64.8	Beet pulp [2,3], beet molasses 2 gallons, amyl acetate 3 ounces	51.6
Beet molasses 2 gallons, amyl acetate 3 ounces, salt 5 pounds	64.3	Beet molasses 2 gallons, amyl acetate 3 ounces	51.4
Cane molasses 2 gallons, amyl acetate 3 ounces	63.3	Wet bran only (check)	50.9
Cane molasses 2 gallons, amyl acetate 3 ounces, salt 5 pounds	61.4	Amyl acetate 3 ounces	49.2
Wet bran only (check)	61.1	Cane molasses 2 gallons, amyl acetate 3 ounces	48.2
Prepared screenings [4]	59.1	Minimum significant difference	6.6
Salt 5 pounds	55.9		
Salt 5 pounds, amyl acetate 3 ounces	54.8		
Beet pulp [2,3], salt 5 pounds, amyl acetate 3 ounces	52.6		
Purina sweet roughage,[3] amyl acetate, 3 ounces	42.1		
Minimum significant difference	6		

[1] Except where otherwise indicated the materials given were added to the standard bait consisting of 1 quart of liquid sodium arsenite (8-pound material) and 14 gallons of water to 100 pounds of bran.
[2] Substituted for bran.
[3] Because beet pulp is more bulky than bran, the sodium arsenite was increased by 50 percent.
[4] A commercial bait to which water only was added.

TABLE 12.—*Comparison of attractiveness of baits with and without miscellaneous attractants in pan-bait tests by several investigators, 1924 and 1932*

Attractant	Investigator	State	Year	Tests	Grasshoppers feeding—With attractant	Grasshoppers feeding—Without attractant	Difference	Difference divided by error
				Number	*Number*	*Number*	*Number*	
Corn oil	Parker	Montana	1924	18	124	133	−9±13.02	0.69
Saccharin	do	do	1924	34	125.9	140.1	−14.2±8.13	1.75
Sugar	do	do	1924	34	123.3	144.0	−20.7±10.91	1.90
Apple oil	Painter, Fluke, and Granovsky	Wisconsin	1924	4	1,735.7	1,661.5	74.2±72.17	1.03
Geraniol	Shotwell	South Dakota	1932	15	93	70	23±14.87	1.55

Table 13.—*Relative attractiveness of various materials and combinations in bran baits, in pan-bait tests by several investigators, 1914–25*

Hunter and Claassen (6), Kansas, 1914

Attractant	Grasshoppers feeding
Experiment 1 (16 replicates):	*Number*
Lemons	12.7
None (check)	10.0
Anise oil	9.8
Vinegar	6.6
Stale beer	6.3
Minimum significant difference	2.4
Experiment 2 (17 replicates):	
Lemons	12.0
Plain sirup	10.0
None (check)	9.9
Stale beer	9.4
Anise oil	7.7
Vinegar	7.5
Oranges	7.0
Minimum significant difference	2.9

Ford and Larrimer (4), Indiana, 1921 (5 replicates)

Attractant	Grasshoppers feeding
	Number
Molasses	497.6
Apple, molasses	480.0
Lemons, molasses	399.8
Wet bran alone	386.8
Oranges, molasses	373.0
Fusel oil, molasses	309.8
Anise oil, molasses	307.8
Minimum significant difference	121.9

Parker (11), Minnesota, 1923

Attractant	Grasshoppers feeding
Experiment 1 (5 replicates):	*Number*
Amyl acetate, salt, molasses	68.9
Salt	66.4
Amyl acetate, molasses	65.4
Molasses, salt	64.2
Apple flavoring, salt, molasses	59.8
Molasses	52.0
Butyl acetate, salt, molasses	51.2
Lemons, molasses, salt	49.0
Apple flavoring, molasses	44.8
Butyl acetate, molasses	43.0
Lemons, molasses	42.8
Minimum significant difference	17.7
Experiment 2 (6 replicates):	
Amyl acetate, molasses	283.8
Amyl acetate	233.3
Propyl acetate, molasses	224.8
Butyl acetate, molasses	223.3
Lemons	197.0
Butyl acetate	193.5
Lemons, molasses	190.1
Propyl acetate	184.8
Apple flavoring, molasses	178.8
Apple flavoring	167.6
Minimum significant difference	44.3

Parker and Seamans (13), Montana, 1919 (3 replicates)

Attractant	Grasshoppers feeding
	Number
Amyl acetate	126.3
Vanilla extract	80.3
Watermelon	58.7
Salt	52.3
Molasses and salt	51.7
Vinegar	51.0
Oranges	50.6
Apples	50.6
Cantaloup	48.7
Bananas	43.3
Lemons	42.0
Lemon extract	37.0
Minimum significant difference	31.3

Parker, Montana, 1924 (23 replicates)

Attractant	Grasshoppers feeding
	Number
Calcium chloride	200.5
Corn oil, amyl acetate	191.7
None (check)	190.4
Corn oil, amyl alcohol	181.6
Molasses, salt, amyl acetate, water (standard bait)	140.0
Calcium and sodium chlorides	107.8
Minimum significant difference	71.2

Lockwood and Shotwell, Montana 1924, 1925

Attractant	Grasshoppers feeding
	Number
Experiment 1 (10 replicates):	
Amyl acetate	258
None	258
Propyl acetate	256
Nitrobenzene	240
Butyl acetate	227
Minimum significant difference	31.7
Experiment 2 (13 replicates):	
Amyl acetate	77
None (check)	71
Butyl acetate	68
Apple flavoring	68
Propyl acetate	67
Lemons	65
Nitrobenzene	62
Minimum significant difference	10.2

TABLE 14.—*Relative attractiveness of various combinations of poison and attractants in pan-bait tests by Swenk and Wehr (19), Nebraska, 1928*

Experiment 1 (6 replicates)			Experiment 2 (6 replicates)		
Poison	Attractant	Grasshoppers feeding	Poison	Attractant	Grasshoppers feeding
		Number			*Number*
White arsenic (refined).	Amyl acetate	227.0	White arsenic	Oranges	336.5
Paris green	Amyl acetate, molasses.	205.0	Calcium arsenite	Lemons, molasses	289.7
White arsenic (refined).	Lemons, molasses	202.7	Paris green	Lemons, salt	284.2
Paris green	Oranges, molasses	198.2		Lemons	277.7
	Lemons, molasses	187.3		Amyl acetate, salt	246.2
	Amyl acetate, molasses, salt.	180.0		Lemons, molasses	243.3
	Lemons, molasses, salt.	153.8		Lemons, molasses, soap.	200.5
Crude arsenic	Lemons, molasses	152.5		Horse manure, lemons, salt.	185.2
	Amyl acetate	148.0	Sodium arsenite	Anise oil, molasses	135.3
	Anise oil, molasses	136.8	Minimum significant difference.		68.9
Minimum significant difference.		69.9			

TABLE 15.—*Relative attractiveness of various quantities of amyl acetate, butyl acetate, and nitrobenzene in pan-bait tests by Shotwell (8 replicates), Montana, 1924*

Quantity of attractant (ounces)	Grasshoppers feeding on bait containing—		
	Amyl acetate	Butyl acetate	Nitrobenzene
	Number	*Number*	*Number*
1	58	61	49
2	55	59	55
3	72	56	46
4	59	46	58
5	60	60	56
Grasshoppers feeding on check bait (bran-arsenical-water)			46
Minimum significant difference			14.9

VALUE OF ATTRACTANTS IN BAITS

Many control campaigns have been successfully carried out without the use of any attractants other than the moist bran itself. In Cascade County, Mont., in 1928 about 38,000 pounds (wet weight) of poisoned bran, with no other attractants, were used on 2,250 acres with an estimated saving of crop valued at $33,750. In 1933, 200 tons of poisoned bran were used, without attractants, on an infested area of 75,000 acres in Imperial County, Calif., with good results.

In North Dakota in 1928 the writer made large-scale field tests in which about 3,400 pounds (dry weight) of poisoned bait were scattered on seven farms, no attractant being used other than the wet bran. The bait was spread around the edges of the fields under exceptionally rainy conditions during June and July, to keep hoppers from moving in and taking the crops. The bran mash had to compete in attractiveness with rank vegetation and green crops such as wheat, oats, barley, alfalfa, beans, and other vegetables. In every case crops were saved, the control ranging from 70 to 80 percent, and the growers got a return of $3,000 to $4,000 on a $40 expenditure for bait materials.

In view of the results with molasses, salt, amyl acetate, and other substances and the excellent results obtained with a bait consisting only of bran or bran and sawdust, arsenical, and water, it appears improbable that these so-called attractants add much value to grasshopper baits. This simple bait has been used during years of abundant rainfall in competition with all kinds of green plants and in the State-wide campaigns of 1937, 1938, and 1939 and has proved efficient when scattered properly. Some extension workers wish to continue the use of these attractants because of the psychological effect on the farmer, but the cost of the bait is materially increased without actually improving its effectiveness.

Carriers

SAWDUST

To reduce the cost of bait, old sawdust is sometimes substituted for a portion of the bran. In a pan-bait experiment to show the effect of such substitution (table 16), baits containing sawdust were in all cases less attractive than all-bran baits, and the attractiveness decreased as the proportion of sawdust was increased. In plot-and-cage tests (table 24) there was no significant difference between all-bran baits and baits containing 50 percent of sawdust.

Table 16.—*Relative attractiveness of bran and sawdust and mixtures of the two in pan-bait tests by Lockwood and Shotwell, Montana, 1925*

Bait (32 replicates)		Grasshoppers feeding
Bran	Sawdust	
Percent [1]	*Percent* [1]	*Number*
100	0	65
75	25	58
50	50	47
25	75	35
0	100	23
Minimum significant difference.		10

[1] These percentages pertain to bulk.

The results of a laboratory-cage experiment comparing baits containing all bran and all sawdust and a half-and-half mixture, with and without oil or molasses, are shown in table 24. The bran-sawdust mixture was equal in effectiveness to all bran in both oil and molasses baits, but all bran was better than all sawdust. Dry bran gave much better results than dry sawdust. Sawdust with molasses was much better than either sawdust with oil or dry sawdust. The three all-sawdust baits were the least effective of all those tested.

All these experiments show the superiority of bran over sawdust as a carrier in baits, and that if sawdust is used it should be mixed with at least an equal quantity of bran. In recent State-wide campaigns, however, a mixture of 1 part of bran to 3 parts of sawdust was used successfully in most areas, although some poor results were obtained in irrigated alfalfa and in areas of heavy rainfall and dense vegetation. There have also been cases where all-sawdust baits containing molasses have proved effective after repeated applications. In contrast to bran, sawdust itself is not a desired food, but the moisture makes wet sawdust attractive to the grasshoppers. Wet sawdust alone may therefore be sufficient under extremely dry conditions, but in the presence of heavy, green, succulent vegetation bran is necessary. The addition of sawdust to wet bran prevents it from lumping and thereby causes it to spread in a thinner layer and in more uniform flakes.

DRY BRAN

Grasshoppers like dry bran (table 17), and if a poison that will adhere to the particles of bran can be mixed with it, a good bait results. In some laboratory-cage tests powdered barium fluosilicate proved better than any of the other poisons (table 23). Sodium fluosilicate and sodium arsenite were more granular and, when viewed under the microscope, were found not to adhere to the bran particles as did the more finely divided barium fluosilicate. When dry bran was used, there was a better kill with barium fluosilicate than with either sodium arsenite or sodium fluosilicate.

TABLE 17.—*Relative attractiveness of dry bran, bran and water, and various attractant-toxicant combinations in pan-bait experiments by Shotwell, South Dakota, 1932*

Experiment 1 (9 replicates)		Experiment 2 (15 replicates)	
Bait	Grasshoppers feeding	Bait	Grasshoppers feeding
	Number		*Number*
Dry bran	274	Cane molasses, sodium fluosilicate, bran, water	124
Bran and water	197	Cane molasses, amyl acetate, sodium arsenite, bran, water	110
Cane molasses, sodium fluosilicate, bran, water	184	Cane molasses, sodium aresnite, bran, water	82
Cane molasses, amyl acetate, sodium arsenite, bran, water	180	Bran and water	70
Cane molasses, sodium arsenite, bran, water	140	Sodium arsenite, bran, and water	63
Sodium arsenite, bran, and water	104	Dry bran	63
Minimum significant difference	90	Minimum significant difference	30

In plot-and-cage tests in North Dakota (table 24) there was no significant difference between dry and wet bran except where a somewhat granular sodium fluosilicate was used with the dry bran, when the results were in favor of the wet bait. In these tests also the dry bran-barium fluosilicate bait gave about as good results as any.

OTHER CARRIERS

Other materials that have been used successfully as carriers to replace all or a part of the bran are beet pulp, cottonseed hulls, and citrus pulp. These products are important in certain localities because of their availability in large quantities. Cowan in Colorado found beet-pulp baits to be less attractive than those made with bran, but not sufficiently so to ban their use when cost and availability were considered (table 11). There appear to be no published experimental data regarding the use of cottonseed hulls and citrus pulp. Other substances, however, such as oat hulls, ground straw, and pea bran, have not proved of any use. Grasshoppers will chew on many substances, but they definitely prefer those that are soft in texture and are able to absorb water.

Toxicants

The toxicants considered here for use in poisoned bait are the various grades of arsenic trioxide commonly called white arsenic, sodium arsenite and its aqueous solution (usually sold as liquid sodium arsenite), paris green, barium fluosilicate, and sodium fluosilicate. The crude form of white arsenic was used most commonly because of its availability, and often in the bait tests a distinction was not made between the crude and refined white arsenic. Where reference is made to the experiments of other investigators, the designations given by them are used, but in publications it is believed that all terms such as "arsenic," "crude arsenic," "bag-house arsenic," etc., can be interpreted as meaning products that were essentially arsenic trioxide (As_2O_3).[6]

In some pan-bait tests conducted by the writer (table 17), by Painter, Fluke, and Granovsky, and by Painter and Granovsky (table 18), in which the relative attractiveness of baits with and without an arsenical was studied, a significant difference in favor of baits without arsenic was evident. However, a bait without a poison is of no value in grasshopper control.

TABLE 18.—*Comparison of attractiveness of baits with and without an arsenical in pan-bait tests, Wisconsin 1933*

Investigators	Tests	Grasshoppers feeding on bait—		Difference	Difference divided by error
		With arsenical	Without arsenical		
	Number	*Number*	*Number*		
Painter, Fluke, and Granovsky	14	812.5	994.5	−182.0±20.89	8.71
Painter and Granovsky	6	152.0	203.8	−51.8±29.71	1.74

The relative effectiveness of various poisons has been studied in plot-and-cage experiments by various investigators (tables 19-21). In most cases liquid sodium arsenite was equal to crude white arsenic, but white arsenic was better than the dry sodium arsenite. Paris green was about equal to the white arsenic. Sodium fluosilicate was a more rapid killing agent, but not better than white arsenic or sodium arsenite in the final result. Barium fluosilicate was not so effective as sodium fluosilicate.

[6] The U. S. Bureau of Mines does not classify a product even as crude white arsenic unless it contains more than 90 percent of As_2O_3; 10 years ago the crude products probably averaged about 94 percent, but at present the figure is more nearly 97 percent. Refined white arsenic contains at least 99 percent of As_2O_3. Bag-house white arsenic is a crude form, which is in general more finely divided than the others.

TABLE 19.—*Relative effectiveness of different poisons in baits in experiments by several investigators, 1921–33* [1]

Plot-and-cage tests: Ford and Larrimer (*5*), Indiana, 1921 (8 replicates) — Poison	Mortality	Plot-and-cage tests: Cowan (unpublished), Montana, 1925 (16 replicates) — Poison and quantity	Mortality	Plot-and-cage tests: Cowan (*3*), Colorado, 1931 (12 replicates) — Poison and quantity	Mortality	Laboratory-cage tests, Shotwell, Montana, 1933 (6 replicates) — Poison and quantity	Mortality
	Percent		*Percent*		*Percent*		*Percent*
Paris green	65.8	Crude arsenic 5 pounds	84.6	Paris green 4 pounds	96.1	Sodium fluosilicate 4 pounds	87.8
White arsenic (refined)	63.3	Sodium arsenite (liquid, 8-pound material) 1 quart.	84.3	Sodium arsenite (liquid, 8-pound material) 1 quart.	88.8	Barium fluosilicate 4 pounds	77.4
Crude arsenic	63.3	Check, no poison	16.1	Sodium arsenite (dry) 2 pounds.	86.1	Sodium arsenite 2½ pounds	50.8
Check, no poison	10.1	Minimum significant difference	19	Sodium fluosilicate 4 pounds	82.3	Check, no poison	1.4
Minimum significant difference	6.1			Minimum significant difference	9.4	Minimum significant difference	22.3

[1] Quantities are per 100 pounds of bran.

Table 20.—*Relative effectiveness of various quantities of poison in baits in plot-and-cage tests by different investigators, 192[illegible]*

Swenk (*19*), Nebraska				Painter, Fluke, and Granovsky (*9*), Wisconsin (4 replicates)		
Sodium arsenite (liquid) (3 replicates)		White arsenic (2 replicates)				
Quantity (pints)[1]	Mortality	Quantity (pounds)[1]	Mortality	Poison	Quantity[1]	Mortality
	Percent		*Percent*		*Pounds*	*Percent*
5	86.3	1	76.0	White arsenic	3	92.7
1	84.4	5	71.0		4	92.7
3	80.4	6	70.0		5	91.3
6	80.3	4	61.5	Sodium arsenite (dry)	1	86.0
2	75.3	2	56.5		2	79.3
½	72.3	3	52.5		3	78.7
8	72.3	7	51.0	Check	0	21.0
7	70.0	8	37.5	Minimum significant difference		10.3
4	65.7	0 (check)	9.0			
10	63.7	Minimum significant difference	27.5			
0 (check)	17.7					
Minimum significant difference	19					

[1] Per 100 pounds of bran.

TABLE 21.—*Relative effectiveness of various quantities of arsenic and sodium arsenite, when combined with different attractants in plot-and-cage tests by Painter, Fluke, and Granovsky, Wisconsin, 1923* [1]

Experiment 1 (4 replicates)

Poison and quantity	Attractant	Mortality
		Percent
Sodium arsenite (dry) 2 pounds.	Molasses 2 gallons	76.7
Sodium arsenite (liquid) 1½ pints.	Molasses 1 gallon, salt 5 pounds, sawdust.	73.3
White arsenic 4 pounds.	Molasses 2 gallons	67.2
Sodium arsenite (dry) 1 pound.	do	66.8
Check, no bait		17.5
Minimum significant difference.		14

Experiment 2 (2 replicates)

Poison (quantities in pounds)	Attractant	Mortality
		Percent
Arsenic 4	Lemons 12	95.0
Arsenic 3	do	93.5
Arsenic 5	Soap, 1 pound	93.5
Arsenic 5	Lemons, salt, sawdust and shorts—(85–15).	93.5
Arsenic 5	Lemons	93.0
Arsenic 5	Lemons, salt	86.0
Sodium arsenite (dry) 1	Lemons	82.5
Sodium arsenite (dry) 2	do	82.0
Sodium arsenite (dry) 3	do	71.5
Check, no bait		24.0
Minimum significant difference.		3

Experiment 3 (2 replicates)

Poison (quantities in pounds)	Attractant	Mortality
		Percent
Arsenic 4	Soap	96.5
Arsenic 3	None	92.0
Arsenic 5	Molasses, amyl acetate.	92.0
Arsenic 4	None	90.5
Arsenic 5	None	89.5
Sodium arsenite (dry) 1	None	89.5
Sodium arsenite (dry) 3	None	86.0
Arsenic 4	Sawdust and shorts (85–15).	84.0
Arsenic 4	Sawdust	82.5
Sodium arsenite (dry) 2	None	76.5
Check, no bait		18.0
Minimum significant difference.		15.3

[1] Bran is the carrier in all baits except where sawdust or shorts is indicated, and all quantities of poison and attractant are per 100 pounds of bran.

The following amounts of the various toxicants, based on 100 pounds of bran (dry weight), are recommended:

White arsenic	pounds	5
Dry sodium arsenite	do	2½
Liquid sodium arsenite, 8-pound material	quart	1
Liquid sodium arsenite, 4-pound material	quarts	2
Sodium fluosilicate	pounds	4
Barium fluosilicate	do	4

Paris green is not used extensively because of its relatively high cost.

For the liquid sodium arsenite the 8-pound and 4-pound materials refer to the quantity of arsenic in the form of arsenious oxide which has gone into the making of 1 gallon of the liquid. Poor results have sometimes been obtained when 4-pound material was being used in the same dosage as the 8-pound material.

Under experimental conditions in small plots some investigators have found that either 1 pint of 8-pound liquid sodium arsenite or 3 or 4 pounds of white arsenic per 100 pounds of bran has been sufficient, and in supervised control campaigns in California satisfactory results have been obtained with 1 quart of 4-pound liquid sodium arsenite. The need of a stronger dosage is probably due to improper manufacture of the poison itself or to inefficient mixing and scattering of the bait.

About the only record of an experiment with amounts of poisoned bait per acre is that of Ford and Larrimer (table 22). They obtained as good results with 7½ pounds per acre as with 20 pounds (wet weight). It is almost impossible, however, to scatter bait by hand at less than 10 pounds per acre. With machine scattering amounts from 5 to 7 pounds have proved successful. In attempting to reduce the quantity per acre, however, one is also likely to do a better job of scattering.

TABLE 22.—*Relative effectiveness of various quantities of poisoned wet bran mash per acre in plot-and-cage tests, by Ford and Larrimer, Indiana, 1919*

Mash per acre (6 replicates)	Mortality	Mash per acre (6 replicates)	Mortality
Pounds	*Percent*	*Pounds*	*Percent*
7½	82.1	12½	76.9
10	81.9	17½	76.1
20	81.7	5	72.6
15	79.3	Check, no bait	23.9
		Minimum significant difference	10.2

OIL BAITS

The worst feature of using poisoned bait in grasshopper control has been the fact that it dries quickly into hard lumps, whereas it is most effective when wet. These pellets are unattractive to grasshoppers, especially to the young nymphs, which cannot eat them. The maximum attractiveness of wet bran lasts only a short time, from 1 to 3 hours depending on conditions. For some time entomologists have considered using a vegetable or mineral oil to keep the bait soft longer (*13a*).

In some laboratory-cage tests in 1933 (table 23) both types of oil were used at rates of 1 and 2 gallons per 100 pounds of dry bran, in comparison with baits containing molasses. The mineral-oil baits were not significantly less effective than the molasses baits. In one experiment palm oil ranked first, but in all cases coconut oil was less attractive than the molasses. Since both these vegetable oils are more expensive than the mineral oil and not available in large enough quantities, they were dropped from further consideration.

TABLE 23.—*Relative effectiveness of various oils and cane molasses in fluosilicate and sodium arsenite baits in laboratory-cage tests by Shotwell, Bozeman, Mont., 1933*

Experiment 1 (6 replicates)			Experiment 2 (5 replicates)		
Poison [1]	Oil or molasses [2] (gallons)	Mortality	Poison [1]	Oil or molasses [2] (gallons)	Mortality
		Percent			*Percent*
Sodium fluosilicate	Cane molasses 2	76.37	Barium fluosilicate	Palm oil 2	79.3
Barium fluosilicate	None (dry bran)	73.98		Cane molasses 2	75.5
	Brown neutral oil 1	71.83		Light mineral oil 1	74.7
Sodium fluosilicate	Coconut oil 1	70.70		None (dry bran)	68.2
Barium fluosilicate	Cane molasses 2	65.90		Heavy mineral oil 1	67.1
Sodium fluosilicate	None (dry bran)	64.45		Light mineral oil 2	65.0
Barium fluosilicate	Coconut oil 1	63.08		Brown neutral oil 2	62.5
Sodium arsenite	Cane molasses 2	49.62		Brown neutral oil 1	62.2
	Coconut oil 1	46.28		Coconut oil 1	53.2
	None (dry bran)	42.40		Coconut oil 2	43.3
Check, no bait		8.05	Check, no bait		5.0
Minimum significant difference.		6.04	Minimum significant difference.		13.3

[1] Sodium and barium fluosilicate were used at the rate of 4 pounds and sodium arsenite was used at 2½ pounds per 100 pounds of bran.
[2] In the baits containing molasses wet bran was used.

In plot-and-cage tests with various bait combinations (table 24) a cheap grade of lubricating oil with white arsenic and bran ranked first. There was no significant difference when either barium or sodium fluosilicate was used in place of white arsenic in the oil baits. In these tests only one collection was made, and that directly after the first feeding period of 3 hours to give the wet bait an equal chance with the oil. All the oil baits were made up at the beginning of the experiment and used when needed, that is, for over a month. The wet mash had to be freshly mixed for each test.

To determine the relative effectiveness of oil and molasses baits over a period of time, two baits of each type were scattered on experimental plots in North Dakota, and grasshoppers from each plot were collected and caged at the end of the first day's feeding, and at 24-hour intervals thereafter until five collections had been made. From counts in each collection over a period of 3 days after caging, the mortality for each of the 5 days the baits lay on the ground without being replenished was calculated. The plots were arranged so that fresh hoppers were moving in every day from adjacent areas and there could be no crossing over from one plot to another. The results are given in table 25. The oil baits were better than the corresponding molasses baits for all five collections. The oil bait containing sodium fluosilicate was significantly better on all days, and the oil bait containing white arsenic significantly better only on the second and fifth days. The oil bait containing sodium fluosilicate was better than that containing white arsenic in every case, but not significantly so. In the molasses mixtures the two poisons were equal in effectiveness.

TABLE 24.—*Relative effectiveness of various combinations of poison, bran or sawdust, and oil or molasses [1] in two experiments by Shotwell, 1933 and 1934*

Plot-and-cage tests, North Dakota, 1933 (13 replicates)			Laboratory-cage tests, Bozeman, Mont., 1934 (4 replicates)		
Poison (quantities in pounds)	Other ingredients	Mortality	Poison	Other ingredients	Mortality
		Percent			*Percent*
White arsenic 5	Oil [2] 2 gallons, dry bran.	78.7	Sodium fluosilicate 4 pounds.	Fuel oil, bran-sawdust (50-50).	98.0
Sodium arsenite 2½	Amyl acetate 3 ounces, wet bran.	77.7		Fuel oil, bran	96.0
White arsenic 5	Dry bran	77.6		Cane molasses, bran-sawdust (50-50).	94.4
Sodium arsenite 2½	Cane molasses 1½ gallons, wet bran.	76.6		Cane molasses, bran.	84.3
Sodium arsenite 2½	Wet bran	75.6		Dry bran	73.1
Sodium fluosilicate 4	Oil 2 gallons, dry bran.	75.0		Cane molasses, sawdust.	72.1
Sodium arsenite 2½	Bran-sawdust (50-50) wet.	74.3		Fuel oil, sawdust	46.9
Barium fluosilicate 4	Oil, 2 gallons, dry bran.	72.4		Dry sawdust	35.5
Sodium fluosilicate 4	Wet bran	72.0	Check, no bait.		16.3
Barium fluosilicate 4	Dry bran	71.1	Minimum significant difference.		9.0
Sodium fluosilicate 4	do	67.8			
Barium fluosilicate 4	Wet bran	67.2			
Check, no bait		15.4			
Minimum significant difference.		8.7			

[1] All quantities are per 100 pounds of dry bran.
[2] The oil used in the plot-and-cage tests was a cheap grade of lubricating oil, Society of Automotive Engineers viscosity 40.

TABLE 25.—*Relative effectiveness of oil and molasses baits after standing on the ground for several days in plot-and-cage tests by Shotwell, North Dakota and Montana, 1933 and 1934*

COMPARISON OF OIL AND MOLASSES, NORTH DAKOTA, 1933 (6 REPLICATES)

Bait	Mortality of grasshoppers collected on indicated day after baiting				
	First day	Second day	Third day	Fourth day	Fifth day
	Percent	*Percent*	*Percent*	*Percent*	*Percent*
Sodium fluosilicate, oil	95.2	85.6	80.8	70.5	75.1
White arsenic, oil	85.4	81.3	64.6	60.0	65.5
Sodium fluosilicate, cane molasses	75.5	72.7	51.9	55.6	48.8
White arsenic, cane molasses	77.8	72.6	56.9	50.3	48.6
Check, no bait	35.5	36.0	38.2	40.3	41.8
Minimum significant difference	13.4	7.7	17.5	19.3	14.9

COMPARISON OF CRUDE AND REFINED OILS AND MOLASSES, MONTANA, 1934 (2 REPLICATES)

Sodium fluosilicate, refined oil	71	41	52	45	
White arsenic, molasses	62	52	47	39	
Sodium fluosilicate, molasses	59	57	53	32	
White arsenic, refined oil	55	29	29	9	
Sodium fluosilicate, crude oil	52	69	52	47	
White arsenic, crude oil	15	9	8	0	
Check, no bait	10	10	2	6	
Minimum significant difference	33.4	30.8	21.4	41.2	

Further laboratory tests were made to establish the fact that the oil baits were more effective over a period of time than were the wet molasses baits. Quantities of both molasses and fuel-oil baits were prepared, and portions of each were used fresh in the cages, while other portions were allowed to dry for 1, 2, 3, 4, and 5 days before being placed in the cages. Table 26 gives the results. Contrary to the finding in plot-and-cage tests, there was no significant difference between oil and molasses baits even after 5 days' drying.

TABLE 26.—*Comparison of fuel-oil and cane-molasses baits when fresh and after standing for several days in laboratory-cage tests by Shotwell, Bozeman, Mont., 1934 (10 replicates)*

Type of bait	Mortality of grasshoppers fed fresh bait	Mortality of grasshoppers fed bait that had stood—				
		1 day	2 days	3 days	4 days	5 days
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Oil	88.1	90.3	92.8	90.4	87.4	89.9
Molasses	87.4	84.8	88.0	90.6	85.8	82.8
Check, no bait	10.4	22.9	5.4	7.1	8.6	8.5
Minimum significant difference	4.3	10.7	4.0	3.5	7.8	6.6

Oil baits were used in the regular control work of the experiment station at Dickinson, N. Dak., with good results. A large batch was mixed at a time, for use when needed, but it was still soft and crumbly several days after application. Hoppers were observed feeding on the baits for a week to 10 days after it was applied. Another important advantage of oil bait is that it can be scattered with little regard to air temperature. It is not, of course, scattered on rainy days.

In the course of these experiments the question arose as to whether strong-smelling mineral oils could be used in place of the more expensive refined oils. Laboratory-cage experiments were therefore carried on in which baits containing refined oil and various types of crude oil were compared with a molasses bait (table 27). There was no significant difference between the oils, and all seemed to be better than the molasses bait. In this connection it might be mentioned that oiled roads do not repel grasshoppers, for the hoppers congregate on them in outbreak areas.

TABLE 27.—*Relative effectiveness of various types of mineral oil and molasses in baits containing sodium fluosilicate* [1] *in laboratory-cage tests by Shotwell, Bozeman, Mont., 1934*

Experiment 1 (7 replicates)		Experiment 2 (10 replicates)	
Oil or molasses	Mortality	Oil or molasses	Mortality
	Percent		*Percent*
Crankcase oil	94.4	Diesel oil	83.1
Refined oil	93.2	Crude oil	80.7
Fuel oil (distillate)	92.2	Molasses	80.2
Cane molasses	83.1	Check, no bait	10.9
Check, no bait	22.4	Minimum significant difference	8.3
Minimum significant difference	8.2		

[1] Sodium fluosilicate was used at the rate of 3 pounds and the oils and molasses at 2 gallons per 100 pounds of bran.

Laboratory-cage experiments are not conclusive, because they do not reproduce outdoor conditions. In contrast to the hard pellets that fall in the field, the small quantity (0.2 gm.) of hard, dry molasses bait is pretty well broken up when scattered in the bottom of the cage. Oil bait was therefore tested in the field under campaign conditions. At Havre, Mont., in May 1934, 20 tons of bait containing crude oil were furnished a number of farmers, who were organized to use it in their control program. Several tons were scattered, but practically no kills were obtained.

A reason was then sought for the failure of the oil bait. The crude oil used contained a great deal of sulfur, and one chemist said that the sulfur had combined with the white arsenic to form an insoluble and harmless sulfide. Since the same crude oil with sodium fluosilicate had given good results in laboratory tests earlier in the spring (table 27), sodium fluosilicate was added to the rest of the already mixed crude oil-arsenic bait. The good results obtained showed that the crude oil was not acting as a repellent. Further field tests indicated that something in the crude oil-arsenic mix was rendering the bait ineffective.

White arsenic and sodium fluosilicate were then used in combination with both refined oil, containing little sulfur, and the crude oil, containing a large quantity of sulfur, as well as in molasses baits, in plot-and-cage tests in Montana. Collections were taken from each plot on 4 successive days. The results are given in table 25. No significant difference was shown between the best oil baits. In no collection was the arsenic-crude oil mix much better than no bait at all. The crude oil-sodium fluosilicate, the refined oil-arsenic, and the refined oil-sodium fluosilicate baits proved as effective as either of the molasses baits. The results of these experiments indicate that there is some basis for the opinion that the crude oil affected the toxicity of the arsenic.

In further laboratory-cage tests (table 24) sawdust and oil was compared with bran and oil. The sawdust and oil was not so good as the sawdust and molasses, and a mixture of bran and sawdust ranked at the top when used with either oil or molasses.

Not enough work has been done with mineral-oil baits to justify a recommendation for their general use, although Canadian investigators and others in the United States have reported favorably on them. In 1937 Illinois used 3,088 tons of mineral-oil bait in a control campaign, with good results.

DIFFICULTY IN APPRAISAL OF RESULTS BECAUSE OF POPULATION CHANGES

During every campaign, in spite of the best instructions and careful organization, reports come in from reliable sources that the poisoned bait is not doing any good. These reports are usually based on a farmer's observation that damage is not prevented and the grasshopper population is apparently not reduced. The general belief that immediate and excellent results may always be expected from one application of the poison is a mistaken one, and usually arises from "pep meetings" where the desire to get something done prevents a plain statement of facts regarding the situation.

Field experiments carried on at Dickinson, N. Dak., in 1933, show in a general way what effect one application of poisoned bait may have on the grasshopper population. Collections were made by the sweeping method (p. 8) before the application and every day for 5 days thereafter. The plots ranged from 1 to several acres in size and included all kinds of crops. Sweeps were also made in similar unbaited check plots located close to the baited plots.

In table 28 the average changes in the original population, on the basis of the number of plots, for the 5 successive days are shown for both the baited and unbaited plots. In addition, population differences for the same number of days are given for each of 10 unbaited plots, arranged chronologically according to the first observation; these data are in the nature of a survey of conditions in the unbaited area.

These experiments were conducted during part of the hatching season, June 9 to 26, when it was very hot and there was considerable movement among the nymphs. Very little difference in effectiveness is shown among the various baits when the check plots and the number of replications are taken into consideration. The average reduction in population on the baited plots ranged from 18 to 83 percent. Six out of the ten unbaited plots showed, on the whole, an increase in population, with daily changes ranging from —49 to +145 percent or, stated another way, from 51 to 245 percent of the original number. Such fluctuations are probably one reason why farmers become discouraged when they see little difference in population, or even an increase, after one application of bait, and say that it will not work. On the plot treated with bait containing beet molasses there was a decrease of only 18 percent on the last day of the count, while on the corresponding check plot there was an increase of 145 percent. No farmer would appreciate the 18-percent reduction, although in reality there may have been a total mortality of 163 percent of the original number on the poisoned plot. On the other hand, a maximum reduction of 83 percent was observed on the plot treated with amyl acetate bait and a maximum reduction of 48 percent on the corresponding check plot. Therefore, the actual mortality may have been only 40 percent, although it appeared to be much higher. When it is realized that the grasshopper populations with which the farmer has to contend are extremely changeable, it is little wonder that he may be either highly elated over his poisoning operations or much disgruntled. If he is given the facts in the first place, he will know what to expect. If everyone realizes that grasshopper control is a continuous fight from start to finish and yet pays big dividends, a better attitude will result.

TABLE 28.—*Percentage changes from original populations of live grasshoppers on baited and unbaited plots as estimated by the sweeping method on each of 5 successive days after one application of bait in tests by Shotwell, Dickinson, N. Dak., June 1933*

Bait[1]	Tests	Average counts from baited plots						Average counts for corresponding unbaited plots						Individual observations on 10 unbaited plots						
		Original count	Increase (+) or decrease (−) from original count					Original count	Increase (+) or decrease (−) from original count					Date of first observation	Original count	Increase (+) or decrease (−) from original count				
			First day	Second day	Third day	Fourth day	Fifth day		First day	Second day	Third day	Fourth day	Fifth day			First day	Second day	Third day	Fourth day	Fifth day
	Number	*Number*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Number*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	June	*Number*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Sodium fluosilicate, oil	7	102	−34	−51	−45	−59	−58	89	+9	+16	+40	+7	+9	9	168	...	+23	+4	−45	−13
Barium fluosilicate, dry bran	6	92	−31	−28	−40	−49	−53	92	+10	+25	+48	+17	+19	10	64	+14	+6	+16	+11	+145
Sodium fluosilicate, cane molasses	3	69	−36	−23	−37	−52	−35	94	+27	+35	+36	+7	+48	12	114	+27	+18	+18	−3	+12
Sodium arsenite, cane molasses	3	108	−46	−55	−64	−56	−64							12	54	+50	+44	+65	+22	+22
Sodium arsenite, beet molasses, amyl acetate	1	51	−63	−65	−63	−53	−39	64	+14	+6	+16	+11	+145	13	65	+3	+6	+109	+28	+3
Sodium arsenite, beet molasses	1	28	−43	−29	+11	−20	−18							14	70	+11	+111	+120	+108	+31
Sodium arsenite, amyl acetate	1	74	−61	−55	−57	−65	−54							15	113	−8	−22	−9	−16	−17
Sodium arsenite	1	38	−34	−53	−24	−21	−55	54	+50	+44	+65	+22	+22	17	147	+8	−33	−9	−49	−48
Sodium arsenite, bran-sawdust (50-50)	2	84	−61	−51	−32	−64	−60	72	+20	+2	+69	+5	−12	19	78	+38	−1	+29	−18	−37
Sodium arsenite, amyl acetate	1	164	−77	−81	−83	−73	−58	147	+8	−33	−9	−49	−48	21	61	+5	+31	+38	+43	136

[1] All baits contained bran.

PRECAUTIONS IN HANDLING POISONED BAIT

White arsenic is a fine dust and may enter the lungs and skin of workers engaged in mixing bait and cause serious toxic effects. To prevent this the following precautions are recommended: (1) A complete change of clothing and a bath after each day's work; (2) daily washing of garments worn while mixing bait; (3) wearing firm-texture coveralls, heavy shoes (not oxfords), and gauntlet-type leather gloves with soft cotton gloves inside. The coveralls should be fastened tightly around shoe tops and wrists and have pockets sewed shut.

When liquid sodium arsenite is used there is less danger of skin irritation, but continued contact with the moist bait may result in burns if workers are careless. Workers mixing this type of bait should take the following precautions: (1) Grease the hands frequently with petrolatum, lanolin, or axle grease and work it under the fingernails; (2) wear heavy rubber or well-oiled leather gloves; (3) when lifting sacks of wet bait wear waterproof aprons; (4) if clothing becomes damp from contact with bait, remove the clothing and wash it thoroughly before wearing it again; (5) bathe the entire body thoroughly after each day's work.

Similar precautions should be taken when scattering the bait.

Mixed-bait containers should be labeled "POISON" in large letters. Sacks of bait, as well as liquid from seepings or washings, should be kept inaccessible to livestock and children. Poisoned bait scattered thinly in flakes is never picked up by livestock in sufficient quantities to cause poisoning, but if it is scattered in lumps and in larger quantities per acre, animals may eat it with disastrous results.

BAIT MIXING

To obtain good results with poisoned baits it is important that the mash be well mixed. Various mechanical devices have been used. Concrete mixers and rotary structures mounted on axles running diagonally through the box are among the favorite devices, and they give a thorough and uniform mixture. The most frequently used method is mixing by hand with shovels, rakes, or hoes in a tight wagon box or on board or concrete floors. Sometimes the bran and white arsenic are mixed dry before the liquid ingredients are added, but it is better to stir the arsenic into the liquid ingredients before spreading it on the bran. When an insoluble poison such as arsenic is being used in this way, the poisoned liquid must be stirred constantly while it is being added to the bran. When liquid sodium arsenite is used, it is first diluted with the water.

A mixing station was set up in Warren, Minn., in 1932 by Oscar Pearson, grasshopper-control leader in Marshall County, one of the most severely infested areas. The mixing boxes were large enough to handle 500 pounds of the dry material at one time, being 16 feet long, 6 feet wide, and 1 foot deep, with slanting ends, and braced with 2-by-4's both underneath and on the sides. Rakes and hoes were used for mixing the bait. More chopping is necessary to get a thorough mix with a hoe, but when the men preferred hoes they were allowed to use them. From these two boxes a total of 1 ton of mixed bait was turned out, in 100-pound sacks, every 20 minutes. Four, and sometimes six, men worked on each box, one man as supervisor.

During the 1931 outbreak in South Dakota a feed-milling company developed a method of mixing by which the bran, white arsenic, and molasses were run through the mixing machines used in making stock feed. Hot molasses was used in this method. By admitting arsenic at the proper rate into the hot molasses and bran and thoroughly working the mixture over and over again, every particle of bran became impregnated with the arsenic and molasses. This bait was then sacked and shipped in dry form and required only the addition of water before application. This product has some advantages over the home-mixed bait. A better mixture is obtained; the danger from handling arsenic by inexperienced people is eliminated; and the product can readily be obtained from a single source, thus avoiding much delay, which often proves disastrous in grasshopper campaigns.

To keep the bait from drying out into hard lumps, which are unattractive to the hoppers, oil is sometimes mixed with the bran and other ingredients. The oil baits are mixed as follows: To 100 pounds of dry bran laid out on a cement floor 2 gallons of a cheap grade of lubricating oil (S. A. E. viscosity 40) is added and worked into the bran with a rake. There is a tendency for the oil and bran to ball up, and it takes longer to work up the oil mix than it does the water and molasses. The poison ingredient is scattered over the oil and bran, and again the bait is thoroughly worked over.

BAIT SPREADING

In scattering bait it is essential that the mash be spread thinly, evenly, and in such a way that it will fall apart as much as possible into individual flakes. The grasshoppers, especially the young nymphs, prefer the individual flakes of bran, which they can handle much more readily than lumps, and better results have been obtained with flaky material. For example, in North Dakota in the summer of 1933 two farmers used poisoned bait from the same batch on wheat fields less than 2 miles apart in which infestations and other conditions were very similar. They broadcast the mash on the same day and at the same time. However, one farmer spread his bait by hand from the end of a wagon and, in order to make his portion cover the whole field, he used it at the rate of about 7 pounds (dry weight) per acre, scattering the mash very thinly by crumbling it through his fingers. The other farmer had a smaller field and scattered his bait at the rate of about 15 pounds per acre, spreading it with a fire shovel from the end of a wagon. The first farmer obtained from three to four times as great a kill as the second. An examination showed that in the second field the mash had fallen in large lumps whereas in the first field it was much more flaky.

J. C. Russell, county agricultural agent at Beach, N. Dak., who in his long experience with grasshoppers has paid particular attention to the amount of poisoned bait to use per acre, states that he has gotten much better results from 7 to 8 pounds per acre than from 15 to 20 pounds because in spreading it more thinly one tends more to break up the lumps. The most satisfactory amount for general use is about 10 pounds (dry weight) per acre.

Another important consideration in scattering bait is the means by which it can be spread quickly and effectively. There are several methods, each of which has its place under certain conditions. It can be scattered by hand from a container carried on foot or horseback or in the back end of a wagon or truck. One person can cover in 1 hour about 7 acres on foot, 11 acres from a wagon, and 18 acres from a truck. This method is suitable for small fields, uneven ground, fence rows, or patchy infestations. A fast method for hand scattering is for two men to spread bait from the back end of a large truck.

Certain mechanical means for spreading have been developed which involve the use of endgate seeders or lime sowers. These machines will cover a strip 20 feet wide and give an even distribution with the mash well broken up. Of the two, the lime sower is preferred. The rate of spread at a horse walk (2¼ miles per hour) is about 7 acres per hour, which is slower than with other mechanical spreaders. These machines are also likely to become clogged, thus requiring a close watch and frequent correction, which retards progress.

Several types of bait machines involving the principle of the straw spreader on a combine have recently appeared in the large wheat-growing areas of Montana and the Dakotas. The simplest type is a horizontal rotating disk with four upright radial flanges, rigged up on the back end of a truck. Motive power is furnished by connecting it by means of a belt to a drive wheel mounted on the hind wheel of the truck.

Other more complicated machines have been devised. One of the best involves the use of the drive shaft, rear axle, and hind wheels of a discarded automobile, and was devised by Sam McCampbell,[7] extension entomologist of Colorado, who furnished pictures and specifications for its manufacture. Figure 4 shows this type of machine. The shortened drive shaft is used to rotate the spreader disk upon which the bait is dropped. It is placed in such a position that the disk tilts upward toward the rear, producing a wider scatter. Blades fastened to the spreader disk scatter the bait as the disk rotates. The bait is fed onto the spreader disk through an opening in the bottom of a hopper made from a steel oil drum erected on a frame above. An agitator within the drum and fastened to the drive shaft keeps the bait running freely. The machine is pulled by a passenger automobile or a light truck, and the scattering is automatic. For successful operation two men are necessary, one to drive and one to watch the spreading machine and keep it replenished with bait and in good working order. The rate of travel and the size of the opening in the bottom of the hopper regulate the amount of bait used per acre and the rate at which it is applied.

More recently an improved bait spreader of this type was designed by the Bureau of Agricultural Engineering cooperating with the Bureau of Entomology and Plant Quarantine.[8] With these machines bait can be spread at rates up to 50 acres per hour, about 3,000 of them of several types having been developed in Montana alone during the 1934 and 1935 campaigns. The first published description came from this State (*14*).

Where a large area or tall corn is to be treated, the airplane has been used economically and effectively. The rate of application has been from 75 to 100 acres per hour, and the cost, including the bait, from 20 to 30 cents an acre. During past outbreaks involving control in cornfields it has been a problem to scatter the bait so the hoppers would feed on it, for in hot weather they are roosting and feeding on

[7] McCampbell, Sam C. Grasshopper bait spreader. Colo. Agr. Col. Ext. Serv. (864)-36, 3 pp., illus. 1936. [Processed.]

[8] U. S. Bureau of Agricultural Engineering and Bureau of Entomology and Plant Quarantine. Poison bait spreader for grasshopper control. [14] pp., illus. 1939. [Mimeographed.]

the corn plants. If the bait is tossed into the air, as in airplane spreading, it alights on the leaves and in the axils of the leaves, where the hoppers will readily feed on it.

FIGURE 4.—Mechanical spreader for grasshopper bait, Colorado, 1936: *A*, Side view; *B*, rear view.

TEMPERATURE AND TIME OF DAY MOST FAVORABLE FOR BAIT SPREADING

The time of applying the bait is important, because the amount of feeding by the hoppers on the bran mash as it lies on the ground varies greatly with air and soil-surface temperatures and sky and wind conditions. Over a period of 10 years workers at the Bozeman, Mont., laboratory made numerous observations on the number of grasshoppers coming to baits placed on boards or in piepans on the ground (fig. 5). From 6 a. m. to 6 p. m. counts were made at 10-minute intervals, and the air temperature at 4 feet, the soil-surface temperature, and sky and wind conditions were recorded at half-hour intervals. From the total numbers of grasshoppers feeding during each hour the percentage of the whole day's feeding was obtained. Converting to percentages did away with differences in populations from year to year and from place to place. These records were then classified according to the maximum air temperatures for the days of observation. Only complete 12-hour observations were considered.

A total of about 150 days of observations were made in 1923, 1924, 1925, 1931, and 1932. The work was done during the 3 summer

FIGURE 5.—Grasshoppers feeding on poisoned baits in pans. The method used for determining the total number of grasshoppers feeding on the bait each hour during the more active daylight period.

months in the north-central and Yellowstone Valley areas of Montana and the Hamill district of South Dakota. The daily maximum air temperatures ranged from 65° to 105° F.

The results of these observations are summarized in figure 6. In all groups having a maximum air temperature above 70° F. the mean time of feeding occurs before noon, between daily maxima of 70° and 90° the means lie between 11 a. m. and noon with a narrow range of 29 minutes, and in the two groups above 90° the means are successively earlier and farther apart.

For days included in the 60°–70° F. range of maximum air temperatures the feeding was evenly divided between the morning and afternoon. On days when daily maxima ranged from 71° to 90° the greater part of the feeding was in the morning, although it was prolonged enough to warrant poisoning up to about 3:30 p. m. In the groups

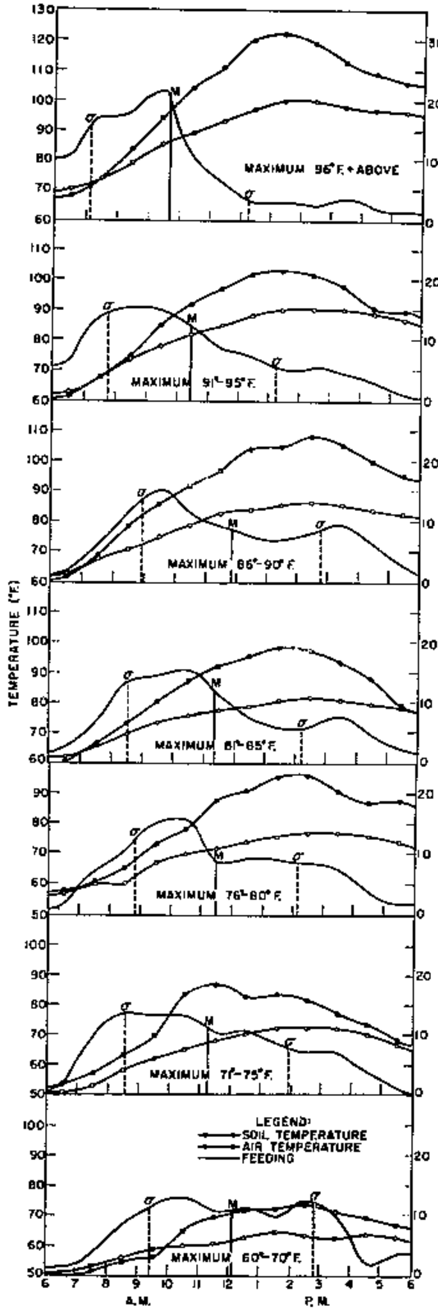

FIGURE 6.—Percentage of the total number of grasshoppers feeding at various hours of the day, classified on the basis of daily maximum air temperatures, Montana and South Dakota, 1923–32. *M* represents mean time of feeding and *σ* the standard deviation of mean time of feeding.

above 90° the feeding period was earlier and shorter. When daily maxima are between 91° and 95° the poison should be scattered before 10:30 a. m., and when they are 96° or above before 9:30 a. m. It is not advisable to spread poisoned baits when air temperatures are below 70° or above 90°, even though hoppers have been observed feeding sparingly on pan baits at temperatures as low as 59° and as high as 96°.

In a series of observations at Hamill, S. Dak., in July 1931, the daily feeding periods, on a mean hourly basis, were recorded for 5 successive days when the air temperatures rose from below 70° F. to above 90°. In the first three days feeding began between 6 and 7 a. m., when the air temperature reached about 70°. The fourth day was hot early, and the grasshoppers began feeding between 5 and 6 a. m., whereas the fifth day was cloudy until 7 a. m. and feeding did not begin until this time; on both days air temperatures when feeding began were close to 80°. During the maximum feeding hour the mean air temperatures ranged from 78° to 85.1°. In four instances the end of the feeding period came when the air temperature reached about 90°. During the second day it ended when the air temperature reached only 83.3°, but the surface-soil temperature at this time was 113°. Hoppers have frequently been observed to leave the ground when the soil-surface temperature reached approximately 113°. There is scattered feeding above 90° and below 70°, but in poisoned-bait control the chief concern is with the main feeding period.

Nymphs and adults ascend the plants to roost during the night, remain there until the rays of the rising sun penetrate to the ground and the air temperature reaches at least 68° F., and then climb down and move about on the ground from plant to plant. When the air temperature reaches 90° or the surface-soil temperature 113°, the hoppers leave the ground, seeking the shady side of plant stalks, fence posts, or buildings. On hot days these two movements usually occur between 6 and 11 a. m. This fact explains why the greater part of the feeding occurs in the mornings on days when the air temperature rises above 90°. Cloudy sky and windy days are not favorable for feeding.

Some farmers have adopted the practice of scattering a little poisoned bait on the ground to observe whether the hoppers are ready to feed. They do not begin broadcasting until feeding is observed and scatter only as long as the grasshoppers continue to feed. This practice works well, but it is safer to govern bait distribution by air temperatures and sky and wind conditions.

Parker (*11*) in 1923 found that the maximum feeding period for *Camnula pellucida* occurred when the air temperature first reached 73°–77° F. Later (*12*) he stated that *Melanoplus mexicanus* under Montana conditions feeds sparingly at bran-mash baits at air temperatures of 55°–63° and soil-surface temperatures of 70°–94°, more actively at air temperatures of 64°–67° and soil temperatures of 95°–103°, and most actively at air temperatures of 68°–78° and soil-surface temperatures of 104°–112°.

During a great part of the summer of 1936 air temperatures did not get below 90° F. during most or sometimes any part of the 24-hour day. In Iowa, Nebraska, Kansas, Oklahoma, Missouri, and Arkansas the hoppers roosted in the trees and shrubs all day, and the current recommendations for spreading poisoned bait in the morning proved ineffective. There seemed to be a movement toward the ground in the cool of the evening, however, and many farmers obtained good results by spreading the poison between 5 and 8 p. m. on the ground in the vicinity of the trees and shrubs.

FUNCTION OF THE ANNUAL GRASSHOPPER SURVEYS IN CONTROL PROGRAMS

In connection with control campaigns the United States Department of Agriculture, in cooperation with State agencies, has for several years conducted annual surveys of grasshopper populations for the purpose of determining in advance the amount of control needed in individual counties and States. At first the surveys were made only in the late summer and fall, when the grasshoppers were in the adult and egg stages. With these surveys it is possible to locate infestations and estimate the amount of control needed the following year, but it is not possible to predict what will happen when hatching commences in the spring. For this reason additional surveys are now made just prior to hatching and during the hatching and nymphal periods as a means of appraising the current grasshopper situation. These nymph surveys have proved an invaluable aid in the allocation, shipment, and timely use of poisoned bait, and they are now considered an essential supplement to the adult and egg surveys.

Adult and Egg Surveys

The method of making the adult and egg surveys was described by the writer (*16*) in 1935. Grasshopper infestations are given ratings from 1 to 5, according to their severity—that is, according to the number of grasshoppers found per square yard and of egg pods per square foot. From the rating given to each stop made in the course of the survey it is possible to compute the percentage of infestation for that stop and the average percentage of crop acreage involved for the entire county. From this percentage of the total grasshopper-susceptible crop acreage of that county, as given by crop statistics, the acreage to be poisoned and the amount of bait required can be computed.

Nymph Surveys

For the nymph surveys from one to three representative points of observation are selected in each infested county, and four or five visits are made to each just prior to and during the hatching and nymphal periods. The main objectives are to determine when hatching will begin, how long it will last, when poisoning should be begun, how the poisoned bait can be used most effectively against the different types of infestation, and the effect of adverse weather conditions on the number of grasshoppers. To obtain these objectives observations are made to obtain the following information:

(1) The number of nymphs per square yard in the field or congregated along margins or on hatching grounds. In dense populations and for first to third instars it is necessary to estimate on a square-foot basis.

(2) The number of egg pods per square foot still unhatched in relation to the number hatched.

(3) The percentage of hatch, based partly on a comparison of the hatched pods with the unhatched pods and partly on the judgment of the observer.

(4) Weather records for studying the effect of weather on hatching and subsequent development within the different grasshopper areas.

(5) The dominant or important species, together with the progress of their development as indicated by the instars present.

(6) The extent of the infestation, which gives some idea of the area of the sources of infestation in relation to the crop or grazing areas.

(7) Nymphal activity, as to whether the young hoppers are (*a*) still along the field margins or on the original hatching grounds, (*b*) moving into crops or migrating from egg beds, or (*c*) distributed throughout cultivated fields or over pastures and range land.

(8) The height of the crop, whether heading, tasseling, or blooming, as an indication of the damage to be expected.

(9) Damage, noted as none, marginal, or general, and expressed as so many rows, feet, or rods for marginal damage and as percentages and kind for general damage.

After data from all these observations have been obtained, a decision can be made, first, as to whether baiting is necessary, and if so whether it must be done immediately or can be delayed. An observation of the numbers of nymphs and unhatched eggs may show that no control is necessary because of the light infestation. If only a portion of the hoppers have hatched and they are still congregated on hatching grounds and no movement toward crop or spreading is imminent, then poisoning operations can be delayed. Immediate action is required if there are more than 10 newly hatched nymphs per square yard, if the percentage of hatch is over 50 percent, if grasshoppers are moving into the crops or spreading from hatching grounds, or if crops are showing damage.

Specific problems will be revealed by the observations. For example, at one place in New Mexico in 1938 *Dissosteira longipennis* (Thos.) was hatching out on a 5-acre egg bed. Observations showed 2,000 nymphs per square yard and 20 unhatched pods per square foot still in the sod. Examinations of eggs indicated that hatching would continue for at least another 15 days. In the meantime the hoppers were spreading from the hatching ground. Scattering poisoned bait on the 5 acres 3 to 5 times during the hatching period would prevent the hoppers from spreading over 1,600 acres at the rate of 40 per square yard, which would be sufficient to take all the grass on the entire area.

One of the fallacies in grasshopper control is the belief that the hoppers on adjacent idle or abandoned land are not the concern of the neighboring farmers. One observation in South Dakota in 1938 showed an average population of 1,500 nymphs per square yard over 160 acres of untenanted reverted land. The spread from this one field could destroy all the grain on 15 sections. Although farmers seem reluctant to poison other people's grasshoppers, it would not be long before the hoppers on these idle lands became their property. If the neighboring farmers would join forces and control the hoppers while the infestations are still localized in such places, they would save their crops from certain destruction.

Predictions as to Beginning and Length of Hatching Period

In determining when hatching will begin and how long it may continue, the factors to be considered are soil temperature, stage of embryonic development, and the number of developmental units necessary for the completion of incubation. Laboratory experiments and field observations have indicated that the minimum effective temperature for egg development is approximately 60° F. Therefore, a soil temperature of 1° above 60° acting through 1 day's time is considered as 1 developmental unit.

It has been found that the number of developmental units necessary for completion of incubation and hatching in the spring ranges approximately from 100 to 400. It has also been observed that eggs gathered in the field can be roughly classified into 4 stages of development. In the first stage the contents of the eggs are a clear fluid, in the second they become coagulated, in the third eyespots develop, and in the fourth there is complete segmentation of the body parts. The number of developmental units necessary for complete development from the beginning of each stage is roughly as follows: Clear fluid 400, coagulated 300, eyespot 200, segmented 100.

The length of time before hatching may be expected is determined by dividing the number of developmental units necessary to complete development from a particular stage by the difference between the average soil temperature and 60° F. If eggs of a given species occur in all stages of development and the average soil temperature is 80° F., hatching will be continuous for at least 20 days, and if the average soil temperature is 70°, hatching will be continuous for 40 days. Unseasonably low temperatures disrupt these calculations, but the method does give some idea of what to expect concerning the time of hatching.

In general, it can be estimated that eggs still in the first stage will hatch within 20 to 25 days after soil temperatures above 60° F. occur daily, in the second stage within 15 to 20 days, in the third within 10 to 15 days, and in the fourth within 5 to 10 days unless already advanced to the point of hatching.

This type of information enables one to determine in the spring how much time is available in which to prepare for poisoning the hoppers when they appear. It also gives some idea of how hatching may be prolonged and baiting delayed, and the number of applications of bait that may be needed to check a spread from the hatching grounds.

BAIT APPLICATIONS IN RELATION TO THE HABITS OF THE GRASSHOPPERS AND TO FARM PRACTICES

When the farmer begins to fight grasshoppers on his own farm, he must realize that vigilance and a knowledge of what to expect, and where to expect it, are more than half the battle. This involves some technical knowledge of the life history and habits of grasshoppers.

Young hoppers remain close to their hatching grounds for some time after hatching. Hatching may extend over a period of 6 weeks. Usually it is not necessary to poison immediately newly hatched nymphs noticed along the edges of the field, for under ordinary circumstances they remain there for several days before moving into the crops. In recent years, however, early droughts have caused newly hatched nymphs to attack crops at once. Under such conditions poisoning operations must be begun immediately, and repeated as often as necessary. This means watching the whole situation from day to day. Unplowed or uncultivated stubble fields are danger spots, since sooner or later the young nymphs that hatch in them are going to move into cultivated crops nearby. Heavy infestations in isolated places should also be cleaned up, because after they have become adults the grasshoppers can travel a long way to reach and damage crops. A farmer who "stubbles in" his grain in grasshopper-infested land has a poor chance of gaining control; moreover, his fields become a menace to the whole community.

When nymphs are migrating they are easily poisoned, and barriers of bait can be set out ahead of them. Such barriers should be placed along that edge of the crop adjacent to the source of infestation, as far into the crop as the hoppers extend, and also some distance into the source of infestation. They should be 100 feet or more wide and should be baited regularly, every day if necessary, at the rate of 10 pounds (dry weight) per acre. A field that is being infested by migration should be constantly watched.

Another critical period occurs during the harvesting of small grains and hay, which is usually in July and August, after the hoppers have become adult. Many farmers have quit poisoning by this time because of their harvesting activities. This is a mistake, because often enough hoppers are left on a field of grain to destroy an adjoining corn crop, which is likely to be just in the tassel and silk stage. When the grain is cut, the pests begin moving into the corn, and it does not take many hoppers to destroy a corn crop. They eat the tassels and silks first, thus preventing fertilization and the formation of kernels. Close examination of corn in fields that looked fine from the standpoint of foliage has revealed from 25 to 75 percent of the kernels undeveloped as a result of the destruction of tassels and silks.

Not only corn, but flax, alfalfa, truck crops, and the later grain crops are endangered by the grasshoppers' moving in from newly cut grain fields and dried-up pastures. Sudden migrations toward greener, more succulent food occur at this time. The grasshoppers are both hungry and thirsty. It has been observed that a person standing in a cornfield during a hot, dry day will attract the hoppers, which move up-wind toward him from distances as great as 30 feet and then attempt to chew his neck, arms, clothing, and even shoes and laces. Wet bran mash is particularly attractive to them and effective under such conditions. The crops remaining after the small grains have been harvested can and should be protected. Furthermore, these crops may be used as veritable traps for poisoning whatever hoppers are left, thereby preventing them from building up again the following year.

Some authorities have advised that it is better to wait until the next year after a crop is gone before applying further control measures, the idea being that perhaps nature will take care of them the next spring. The error of this procedure was demonstrated in 1931 in South Dakota, where cornfields left after all the small grain had been destroyed were heavily infested with grasshoppers. It would have been easy to poison them there, but since most of the county governments were without funds and discouraged, it was deemed advisable to wait until spring. They were fortunate the following spring, for many young hoppers were killed by unfavorable weather conditions.

In 1933, however, their crops were destroyed, and it seems very probable that, had these people poisoned the hoppers in the cornfields during July and August of 1931, they would have prevented some of this destruction. By poisoning 1 female grasshopper in July or August 100 to 300 young hoppers are prevented from developing the following spring.

REDUCTION OF BAITING BY SOIL CULTIVATION

It is well known that stubbled-in fields, that is, fields that are simply disked and sown, are the infestation centers in some grasshopper outbreaks. Most of the species tend to congregate their eggs around the edges of such fields, but some also scatter them if conditions are favorable. *Melanoplus mexicanus* (Sauss.) scatters its eggs more than *M. bivittatus* (Say), *M. differentialis* (Thos.), or *Camnula pellucida* (Scudd.), which crowd their pods together in soddy margins. In outbreak years, however, eggs of all these species are often found scattered through the fields in sufficient numbers to cause a ruinous infestation. With *M. mexicanus* the numbers may reach 100 pods per square foot. This scattering of egg pods increases the difficulty of poisoning the hoppers and in some cases makes it impossible to effect good control.

With this in mind many observations have been made to determine the effect of cultural practices on grasshoppers hatching in the fields. An example of the value of cultivation is taken from a previous bulletin (*15*). A portion of Hill County, Mont., in the fall of 1925 was heavily infested with eggs of *Melanoplus mexicanus*, as many as 18 egg pods being found around the base of a single stub in one wheat-stubble field. This field was plowed and thoroughly worked early in the spring of 1926, before the eggs hatched, and was planted to corn; as a result only a few hoppers issued and they starved to death before the corn came up. In a rye field that was plowed and disked late in the fall few nymphs hatched the following spring. Newly hatched nymphs need food immediately and soon starve if none is within easy reach.

Plowing around the outside of a field and working toward the center after hatching has taken place has been used to good advantage in concentrating nymphs in a small area, where a maximum kill by poisoning can be obtained with a minimum expenditure of labor and material. Strips of plowed ground 50 to 100 feet wide have also been successfully used as barriers to prevent first to third instars from moving into crops from adjacent hatching grounds, on which they can easily be poisoned.

In Ward County, N. Dak., in 1928, most of the hoppers on a 40-acre wheat-stubble field had been congregated on a strip about 30 feet wide and one-half mile long down the middle of the field, by plowing around the outside toward the middle. Hoppers were also congregated along the fence rows at each end of the field. This made a total of about 5 acres of unplowed ground. Over this heavily infested area 100 pounds (dry weight) of bran mash was scattered by hand between 8 a. m. and 12 noon. The following formula was used: Bran 100 pounds, water 10 to 12 gallons, liquid sodium arsenite (4-pound material) 2 quarts. The next day more than 80 percent of the grasshoppers in this field were already dead, and 2 days later practically all the hoppers were dead. It was the fastest kill obtained with poisoned bran mash yet observed by the writer. Heavy rains had fallen previous to the day the poison was applied, the volunteer wheat and other vegetation was very rank in this field, and there was plenty of other food present besides the bran. The poison was spread thickly, but when it is considered that practically all the hoppers from this 40-acre field were congregated on the 5 acres to be poisoned, 100 pounds does not seem to be too large a quantity. It would have required four times as much bran mash, eight times as much time and labor, and four times the cost to poison the entire field, and it is very doubtful whether the percentage of kill would have been so great as that obtained on the 5 acres. The labor of plowing in this case can be considered as negligible, because the field was to have been plowed anyway.

At Dickinson, N. Dak., in 1933 there was a quarter-section of flax stubble sown to wheat. About one-third of this field was plowed, another third was seeded direct, and the remaining third was seeded after double disking. On May 22 a general hatch of *Melanoplus mexicanus* occurred in this field. A count of the hoppers showed in the portion seeded direct from 50 to 100 per square yard, in the disked portion 10 per square yard, and in the plowed portion none. One could distinguish the differently treated portions by the amount of Russian-thistle present. The plowed one-third was practically clean, the disked portion had a general scattering of thistles, and the area seeded direct was densely covered with them.

In northern Montana during the spring of 1934 general recommendations for control by plowing failed, because almost as many hoppers hatched from the plowed as from the unplowed stubble. Upon examination it was revealed that the surface soil was dry and crusty and broke up into lumps when plowed, enabling the hatching hoppers to work their way to the surface. To obtain a satisfactory control the soil must be broken up and packed well, as shown by the following experiment:

On May 18, 1932, at Hamill, S. Dak., a plot 22 by 3 feet was spaded to a depth of 10 inches and then smoothed off to simulate plowed and worked ground. Shallow pie pans, each containing 500 eggs scattered over it, were then buried at various levels beneath the surface of the soil, exact levels being marked by stakes alongside the pans. The dirt filled in over the pans was not packed except by natural conditions. A tight wire-screen cage was placed over each pan, and counts of hatched nymphs were made from time to time. The use of pie-pans made it possible to disinter them later and count the unhatched eggs as a check on the counts of emerging young and also to observe what had happened to those eggs that did hatch. It was believed that in the deeper soil the eggs would hatch but the nymphs would not reach the surface. On July 11 the pans with a layer of 2 to 3 inches of dirt on them were carefully dug up, inverted, and the unhatched eggs counted for each level.

The results, which are presented in table 29, indicate that most of the eggs had hatched at all depths. At depths of 4 to 8 inches the vermiform nymphs could not make their way to the surface and died in their tunnels, most of which were not more than 1½ inches long. Rain had warped the cages placed over the pans at 2- and 3-inch depths and allowed many of the hatched nymphs to escape.

TABLE 29—*Nymphs reaching the surface and unhatched eggs from eggs buried at various depths in soil on May 18, 1932, in tests by Shotwell, Hamill, S. Dak.; 500 eggs buried at each depth*

Depth (inches)	Number of nymphs reaching surface on—												Unhatched eggs
	May 24	May 25	May 27	May 28	May 29	May 30	June 2	June 5	June 6	June 7	June 10, 13, and 18	Total	
2	7	155	5	3	5	0	8	4	3	2	0	192	3
3	1	11	2	6	0	1	6	0	1	0	0	28	8
4	0	0	0	0	0	0	0	0	2	0	0	2	9
5	0	0	0	0	0	0	0	0	0	0	0	0	10
6	0	0	0	0	0	0	0	0	0	0	0	0	17
7	0	0	0	0	0	0	0	0	0	0	0	0	16
8	0	0	0	0	0	0	0	0	0	0	0	0	24

After laying her eggs the female grasshopper leaves a natural tunnel shielded by the walls of the pod for the escape of the hatched nymphs. When eggs are plowed under and buried to a depth of 4 inches or more, this natural means of escape is destroyed. If the soil is moist and crumbly and packs well, plowing eggs under in the field prevents the nymphs from coming out and narrows the required poisoning operations to the edges of fields and to roadsides. Usually these headlands and roadsides are about 3 rods wide, covering 6 acres to a mile of fence. Since there are 2 miles of margin or fence around a quarter-section of land, there are 12 acres of headlands. Plowing a 160-acre field infested with eggs theoretically reduces the amount of land to be poisoned 92 percent.

SUMMARY

The various substances suggested for use in poisoned grasshopper baits have been evaluated by a study of all the available experimental data on such baits that lend themselves to statistical analysis.

Several experimental methods have been used for evaluating bait materials—the pan-bait, plot-and-cage, laboratory-cage, and the sweeping methods, and counts per unit area. The plot-and-cage method appears to be the best for determining differences between baits, although the pan-bait method has given valuable data as to feeding periods, and the laboratory-cage experiments have given important leads for field work. One difficulty in appraising the results of bait applications is due to population changes even from day to day, as observed in unbaited areas.

The substances most commonly advocated for use as attractants in poisoned baits have been molasses, amyl acetate, lemons, and salt. In the experimental work cane molasses showed to better advantage than beet molasses, baits containing the latter seldom being so good as baits without molasses. However, there is little evidence that cane molasses is of value. Amyl acetate was used to replace the more costly lemons, but experimental data do not support the continued use of either of these materials. Common salt was found to be repellent rather than an attractant. Fermented baits were less attractive than unfermented baits, and whey was found to have little value as an attractant. None of the other substances that have been used for this purpose were found to have any value. It was therefore concluded that the inclusion of attractants in poisoned baits adds unnecessarily to their cost.

Although bran has been the usual carrier for the poison, and is shown to be superior to sawdust, which is cheaper, a mixture of equal parts of bran and sawdust may be used, and even greater proportions of sawdust in the drier regions. Dry bran was as satisfactory as wet bran when barium fluosilicate was the poison used. Beet pulp was less effective than bran, but it may be substituted in areas where this material is available.

The toxicants used in bait are white arsenic (crude and refined), sodium arsenite (dry and liquid), paris green, barium fluosilicate, and sodium fluosilicate. Liquid sodium arsenite, crude white arsenic, and paris green were equally effective and better than dry sodium arsenite. Sodium fluosilicate was a more rapid killing agent, and is less harmful to man and animals, but was not better than the arsenicals in the final result. Barium fluosilicate was in general less effective. The following quantities of toxicant per 100 pounds of bran are recommended: White arsenic 5 pounds, liquid sodium arsenite (4-pound material) 2 quarts, sodium fluosilicate 4 pounds. Paris green is not recommended because of its comparatively high cost.

Baits in which mineral oil was used instead of molasses were not significantly less effective than molasses baits, and after lying on the ground for 1 to 5 days the oil baits were more effective in plot-and-cage tests although not in laboratory tests. Crude oils were just as good as the more refined oils. More work should be done with oil baits, however, before they are recommended for general use.

In the effective use of grasshopper baits other factors are important besides the right kind of bait. In the late summer and fall adult and egg surveys are made to locate and determine the extent of infestations, so that the quantities of materials needed the following year can be estimated. In the spring nymph surveys are made to obtain information on hatching and the type of infestation, for use in determining when poisoning should be begun, how the bait can be used most effectively, and as a general aid in the allocation of material.

For a bait to be most effective the ingredients must be thoroughly mixed. Mixing can be accomplished by hand or mechanical means. Furthermore, a method of scattering that will cause the bait to fall apart in individual flakes should be used. On rough ground, field margins, and small fields the bait can be scattered by hand either on foot or from a wagon or truck. The best method for larger areas is the use of spreading machines driven from the rear wheel of a truck or from the drive shaft or upturned rear axle of a discarded automobile. Airplane baiting may eventually prove to be the most efficient, if certain operating difficulties can be overcome. As good results were obtained when the bait was scattered at the rate of 7½ pounds per acre as at 20 pounds.

It is important to scatter the mash at the time when the hoppers are most likely to come in contact with it and will eat freely. Grasshoppers usually begin feeding in the morning as soon as the air temperature reaches 70° F. and the sun's rays penetrate through the crop to the ground, and they continue until sated, or until the temperature reaches 90° or weather conditions become unfavorable.

Stubbled-in crops become foci of infestation in grasshopper outbreaks. Eggs plowed under to a depth of 4 inches either fail to hatch or the vermiform nymphs cannot reach the surface if the soil is well packed. Disking does not prevent all hatching, but it reduces the population. Since plowing prevents hatching, it narrows the requirements of poisoning operations to field margins, reducing the area to be poisoned by 80 to 90 percent.

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