GRASSHOPPER BAITS IN OKLAHOMA

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By

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PREFACE

When the writer began graduate work in entomology in the summer of 1936 the present grasshopper outbreak was in its early stages. While assisting in the testing of baits carried on by the experiment station staff, he became interested in the general problem of grasshopper control.

As the outbreak increased to serious proportions, it was decided by the experiment station staff to investigate several factors influencing grasshopper control under Oklahoma conditions. The writer was placed in charge of field work on grasshopper bait experiments. This work was done during the summers of 1936 and 1937. The majority of the experiments were made in Payne and Woodward Counties.

The general problem of grasshopper bait development and testing was suggested and approved as a thesis subject by Dr. F. E. Whitehead, the writer's adviser. Two general aims were uppermost in this investigation. First, it was desired to test certain successful bait developments of other sections under Oklahoma conditions. Second, it was planned to test as bait materials certain products available in the state in large quantities and at low costs.

The writer wishes to express his appreciation to the following people who aided in doing this work:

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4. Mrs. Elsie Mae Walton made the graphs and assisted in checking the tables.

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TABLE OF CONTENTS

I. INTRODUCTION

As far back as records exist grasshoppers are reported as injuring man's products. The Bible and the writings of the ancient Babylonians, Egyptians and Greeks contain references to the dreaded locusts as pests of agriculture. Although man has had grasshoppers as foes for thousands of years, it has been only in the last century that he has fought anything but a losing battle. Even in modern times, with all the machinery and supplies of a scientific age at his command, the part man plays in controlling such insect pests is but small and temporary to say the most.

The injury done by grasshoppers is a continual and ever-present loss. The general public, however, becomes aware of it only when the insects increase to a devastating number. As early as 1773 there was an outbreak in South California. During the period from 1860 to 1880 the Missouri Valley was ravaged by swarms of the Rocky Mountain Locust or Migratory Grasshopper (Melanoplus mexicanus Sauss.). Since that time grasshoppers have been a recurring problem in the central and western states. During the last decade an almost continual campaign has been waged against them in a number of these states.

Since statehood there have been three grasshopper outbreaks of major importance in Oklahoma. The first of these occurred in 1916, the second in 1925, and the third and most recent in 1936. Generally, these outbreaks continued over a period of two to four years. The last outbreak, beginning in 1936, has continued with undiminished force through 1937 and 1938. In the two years of 1936 and 1937 more than 100,000 bales of cotton, thousands of acres of corn and alfalfa, many shade and fruit trees, and large quantities of truck and garden plants were destroyed.

The attempted control measures for grasshoppers have been many and varied. Some of these such as making noises, planting of poisonous plants, and inoculation with diseases and parasites, have proved ineffectual. Those that are more or less successful are cultural practices, burning, trapping, collecting, spraying, dusting, and poison baits. While several of the above have been practical in Asia and Africa, the most successful method of control in America has been the use of poison baits.

Previous to 1936 no experimental work on grasshopper control had been done in Oklahoma. At the beginning of this outbreak the recommended control method was the so-called "Kansas" or "standard" bait. It consisted of 100 pounds of bran, 2 gallons of molasses, 2 dozen lemons or oranges, 5 pounds of Paris green or white arsenic, and water. This bait is very effective but is also quite expensive. The demand over the country in 1936 for bran soon exceded the supply on hand and prices at once rose from forty to fifty per cent. In recent years cheaper substitutes or diluents for bran have been used, in some states, without materially decreasing the bait's efficiency. Further, the time of day for spreading bait has been changed in many places. Therefore, it was considered of economic value to determine if similiar changes were practical to use under conditions in Oklahoma.

II. REVIEW OF LITERATURE

It is not definitely known just when poison baits were first used in America. Riley (70) reported some experiments made under his supervision in 1877. The baits consisted of flour and Paris green mixed at a ratio of 30 to 1. Both dry and wet mixtures were tried. In general, the workers reported very little success and Riley concluded the baits were not practical.

Though experiments on baits were conducted as early as 1877 and later in 1885, it was not until about 1900 that they were recommended generally by state experiment stations. This is indicated by the fact that Lugger (47), Hunter (40), Bruner (5), and Doten (20) did not list poison baits in their bulletins in discussing control measures.

The development of grasshopper baits has been through efforts of many workers in many different sections over a period of the last sixty years. During this period of modification and change the so-called "Kansas bait", described above, became accepted as a general standard with which to compare other combinations. The constituents of this "standard", and of many other baits, fall into three classes of materials, according to their function. There is always a filler, base or carrier material, such as bran or sawdust. All baits contain a poison of some nature. Generally, certain materials, called attrahents have been added. These were believed to have attractive qualities for grasshoppers.

For the sake of clearness and proper classification it is proposed to review the literature of bait development under the heads of carriers, poisons, attrahents, time of bait applications and feeding temperatures, and miscellaneous developments.

A. CARRIER OR FILLERS

According to Riley (71) and Coquillett (11), bran was first used as a bait carrier in 1885. In that year Coquillett supervised the use of bran-mash bait in California. No more mention of baits is made in literature until 1897 when a bran-arsenic mash was recommended by Lugger (48) in Minnesota and by the experiment station in Kansas (81), for gardens and small areas. In 1902, Woodworth (90) stated that the bran-mash had been used for several years with success against moderately heavy outbreaks in California. The use of bran mash as a control measure spread rapidly after 1900. To illustrate, it was tested and recommended by Bruner (6), Gillette (34), Craig (14), and Hunter (41).

The next important development of baits was made by Norman Criddle (15), of Manitoba, who used fresh horse manure as a carrier in his famous "Criddle Mixture". Gibson (32) reports that this mixture was developed in 1901, but Criddle (16) states that it was first used in the campaign of 1900. Within the next fifteen years the use of "the Criddle Mixture" became somewhat general, though the results were very variable. Among those who tested and recommended the bait were Geismar (31), Washburn (86), Houser (38), Scholl (75), and Merrill (50). Workers that reported the mixture as unsatisfactory were Hunter (41) in California in 1905, Headlee in Kansas in 1912, Milliken (51) in Kansas in 1916, and Ball (1) in Utah in 1915.

During this period, while the "Criddle Mixture" had been popular, the bran-mash bait had been experimented upon by the addition of various attrahents. In general, by 1915 most workers were recommending some form of the "Kansas" or "standard" bran bait. Those reporting bran baits as very satisfactory were Lovett (46), Gibson (33), Hunter (42), Dean (19), Wilson (89), Herrick (37), Morrill (54), Severin (76), Milliken (51), Ford (28), and Parker (58).

The next movement in bait Carrier development was the search for a cheaper substitute or diluent for bran. This movement, beginning about 1915, has continued until the present time. Criddle (33), again the leader, in 1914 reported successful preliminary experiments with sawdust as the carrier. Gibson (33), the following year, after a series of tests, stated sawdust showed great promise. Morrill (55), in Arizona 1918, found that pure sawdust was only 52 per cent as effective as bran, but that a 50-50 mixture of bran and sawdust was as good as the pure bran. Within the next eight years, workers that tested and recommended pure sawdust baits were Davis (18) in Indiana, Parker (60) in Montana, and Granovsky in Wisconsin. Granovsky (36) reported excellent results with pure sawdust in the campaign of 1925. Munro (57) found that a 50-50 mixture of one year-old sawdust with bran gave an effectiveness of 10-12 per cent below the standard. Ford (28) reported results very similar to Munro.

Russell (73) and Granovsky (35) reported a successful formula, consisting of sawdust (85 per cent) and Middlings or shorts (15 per cent). This marked the beginning of a series of experiments conducted by many workers over the country to find a suitable coating material for sawdust or other cheap fillers. Some of those doing this work were Russell (74), Drake (21), and Parker (1937-38, unpublished).

A number of other substitutes or diluents have been tried and recommended. King (43), in 1907, tried a successful bait of finely chopped fresh green grass. Merrill (50) said reports of successful use of alfalfa meal came to him. Swenk (82), in 1918, recommended the use of lucerne or alfalfa meal. Burrell (8) stated the use of mill feed was successful in Washington in 1918. Buckell (7) substituted cow manure for bran in British Columbia. Flint (25) reported that torn up newspaper, soaked in a solution of poison and molasses, gave better results than the standard. Mitchner (52) recorded successful results with finely cut green rye or wheat in Manitoba. Cowan (13) indicated dried beet-pulp had possibilities. Roberts (72), in Nebraska in 1937, reported that pure corncobs and pure cornstalks showed little promise, but that a mixture of either of these with bran was satisfactory.

B. POISONS

There are four poisons that have been used and tested extensively in grasshopper baits. These are, in order of introduction, Paris green, arsenic, sodium arsenite, and sodium fluosilicate. Arsenic (arsenious oxide), the basic formula from which most arsenicals are derived, is very toxic and very cheap. Its chief disadvantage is that it is slow to kill. Paris green (copper aceto-arsenite) is about 55 per cent arsenic. Its main advantage is that of a quick kill. Its disadvantages are that it does not adhere well and that it is relatively expensive. Sodium arsenite, generally sold in solution form, mixes readily and uniformly with the bait. It is very toxic and is cheap. Sodium fluosilicate is a comparatively recent poison used in baits. It has a high toxicity rating and is quick to kill.

Paris green was the poison used in the first grasshopper bait experiments in 1877 as reported by Riley (70). According to Riley (71), arsenic was first used in grasshopper baits in California in 1885. From the appearance of the "Criddle Mixture", in 1900, until about 1920, recommendations for poisons in baits were almost equally divided between Paris green and arsenic. Ford and Larrimer (29), in 1921, found the optimum strengths for these poisons, per 100 pounds of dry bait, to be: Paris green, 2 pounds; white arsenic 3 pounds; crude arsenic 6 pounds. They stated the poisons were all equally effective when used at these strengths. Ballard (2), in Egypt in 1930, found sodium arsenite superior to Paris green and sodium fluosilicate.

Sodium arsenite was used in Africa in locust baits in the latter part of the 19th century. It was first used in this country in grasshopper baits by Washburn (86), in 1911, in the "Minnesota Mixture". In 1923 Corkins (12) firmly established sodium arsenite as a killing agent in baits. He found that the optimum strength, 1 pint (eight pound material) per 100 pounds of dry bait, was as effective as baits containing 5 pounds of white arsenic or 4 pounds of Paris green. Swenk (83) concluded that the addition of molasses to white arsenic baits decreased their efficiency but that it increased the efficiency of sodium arsenite baits. Ford (27) found that hoppers feeding on Paris green lived 35.5 hours, those on white arsenic, 43.9 hours, and those on crude arsenic 50 hours. Richardson (68) determined the median lethal dose of the various poisons for grasshoppers, per gram of body weight, to be: white arsenic, .36 mg.; sodium arsenite, .16 mg.; sodium fluosilicate, .16 mg.; and Paris green, .16 mg. Since 1925, investigators who have tried and recommended sodium arsenite are Granovsky (35), Whitehead (88), Granovsky (35), Richardson (68), Mitchener (53), Drake (21), and Bigger (4).

As stated above, Richardson (68) found sodium fluosilicate to be equal to sodium arsenite in killing power. Mitchener (53) reported sodium fluosilicate as giving 78 per cent mortality, which was not quite as good as sodium arsenite. Parker (66) showed that fluosilicates were as good as white arsenic. Roberts (72) indicates sodium fluosilicate was successful in Nebraska in 1937.

Magnesium sulfate was reported by Frings (30) as a successful bait poison for grasshoppers in 1937. On the other hand, Smith (79) and Roberts (72), both, stated that its killing value was very slight if any.

C. ATTRAHENTS

As far as attrahents are concerned, grasshopper baits are now back where they started in 1877. Riley (70), in 1877, had no attrahent in his bait of flour and Paris green, while Coquillett (11), in 1885, had sugar in his bran-arsenic mash. Coquillett insists emphatically, however, that the sugar had no attractive power for grasshoppers and was put in the bait to cause the arsenic to adhere to the bran. In the years following, sugar or molasses came to be thought of as an attrahent as well as an adherence agent.

At a very early period, baits without any attrahents were recommended by Snow (81), in 1897, Gillett (34), in 1903, and Craig (14), in 1904. Until 1937, there were some workers who at various times recommended only molasses as an attrahent. Some of these were Howard (39), Bruner (6), Woodworth (90), Hunter (41), Washburn (86), Scholl (75), Ford (29), and Drake (21). Ford and Larrimer (28), in 1920, made extensive tests with fruit and molasses. They found that blackstrap molasses increased the attractiveness of plain bran 28 per cent. Morrill (56), on the basis of his own experiments and a summary of other workers' data, concluded, molasses added nothing to the effectiveness of baits. Larrimer (45) found that molasses attracted fewer grasshoppers than either plain water or soap.

Since the introduction of the "Criddle Mixture", salt has been recommended as an attrahent by many investigators. Some of those that indicated it had value in baits were

Geismar (31), Lovett (46), Houser (38), Caesar (9), Granovsky (35), Parker (46), Criddle (15), and Mitchener (52). Pettit (67) reported that an excess of salt was definitely repellant to grasshoppers. Ford and Larrimer (29), after extensive tests on attrahents, found that baits without salt were 23 per cent more attractive than those containing salt. Cowan (13) stated that salt did not add to the attractiveness of baits.

In 1911, Milliken of Kansas started experimenting with citrus and other fruits as attrahents in grasshopper baits. The final result of his work, along with that of Dean (19) and Hunter (42), was the "Kansas" or "standard" formula. To illustrate how generally the value of citrus fruits as attrahents was agreed upon, during the period 1914 to 1920, twenty of twenty-two papers reviewed recommended their addition.

In 1920 Parker and Seamans (58) started the use of cheaper attrahents by discovering amyl acetate as an effective substitute for citrus fruits. Previous to this, in 1917, Morrill (55) had shown there were no significant differences between cantaloupe, oranges, tomatoes, lemons, peaches, and watermelons when used as attrahents. Flint (25) stated that he got better results when 3 pounds of finely ground green beans were added to 25 pounds of bran than when he used citrus fruits. A year later Flint (26) reported there was evidence to indicate that attrahents were not necessary. In 1921 Ford (28) tested 26 flavors and found that no flavor at all and black strap molasses led in a total of 26,496 'hoppers counted. Larrimer (45) in a search for grasshopper repellents found none in a list of 13 tested. Chamberlin (10), in the four years of 1927-28-29-30, using the cage method developed and described by Ford and Larrimer (29), tested thoroughly the effectiveness of various attrahents. Over the four-year period no significant difference was found between the mean mortality of 68.1 per cent for all of the attrahents and 65.6 per cent for the plain water.

D. TIME OF SPREADING AND FEEDING TEMPERATURES

The early writers on grasshopper baits did not state the time of day for spreading. They either assumed that one time was as good as another or they followed the rule of spreading when the 'hoppers were feeding. Dean (19) and Hunter (42) specifically recommended spreading bait between 5:00 and 7:00 o'clock a.m. Ball (1) said to spread either in the late afternoon or preferably in the early morning. As late as 1917 and 1919 Severin (76) and Urbahns (84) stated that the best time to spread was in the late afternoon. Since then practically all entomologists have recommended spreading bait sometime in the forenoon. Granovsky (36) said that the proper time in Wisconsin was at 10:00 a.m.

For a number of years entomologists have known that the feeding of grasshoppers was influenced greatly by the temperature. However, it was not until 1923 that definite temperatures at which various activities occur were determined. In that year Parker (62), working with the Clear-Winged Grasshopper (Camnula pellucida Scud.), by means of pan tests, determined the minimum, optimum, and maximum temperature for feeding on poisoned bait. These were: minimum, 65-68 degrees F.; optimum, 71-77 degrees F.; maximum, not far above 80 degrees F. Parker (63) found the temperature ranges for the lesser migratory locust (Melanoplus mexicanus Saussure) in Montana to be somewhat broader. These temperatures were: minimum, 55 degrees to 63 degrees F.;

optimum, 68 degrees to 78 degrees F.; maximu, not far above 80 degrees F. Langford (44), working with *M. bivittatus*, *M. differentialis*, *M. femur-rubrum* and *Chortophaga viridifaciatus*, found about the same range as Parker did for *M. mexicanus*.

E. OTHER BAIT DEVELOPMENTS

The method of applying bait has undergone at least one distinct change. Coquillet (11), using bran-mash in vineyards, in 1885, placed a teaspoonful of the mash at the base of each vine. Hunter (41) thought the pile method was more effective than broadcasting bait. Much of the early bait was put out in balls. Hunter (42), Geismar (31), and Merrill (50) used the pile or ball method of applying bait. By 1915, however, nearly all recommendations were for broadcasting it.

The rate of applying bait has varied from 3 to 20 pounds per acre. Ford and Larrimer (29), in 1920, determined the optimum amount of bran baits to be from 7½ to 10 pounds, dry weight, per acre. Most recommendations at the present time specify 10 pounds, dry weight, per acre.

For several years various kinds of oils had been speculated upon as possible bait materials. In 1934, Parker (66) reported satisfactory results in preliminary experiments with several oils. Those reported as successful were palm oil, refined heavy mineral oil, refined light mineral oil and low grade lubricating oil (vis. 30). The lubricating oil was found to be as good as the "standard" bait. In 1937, Bigger (4) recommended fresh low grade lubricating oil (vis. 20-30) with solid poison in bran baits.

III. EXPERIMENTAL

A. Attractiveness of Baits and Influence of Temperature and Other Conditions as Shown by Pan Tests.

Members of the genus Melanoplus were by far the most harmful group of grasshoppers in Oklahoma in 1936 and 1937. The dominant species in alfalfa habitats were M. differentialis, M. packardii, M. mexicanus, M. foedus iselyi and M. bivittatus. The most abundant in cotton fields were M. mexicanus, M. differentialis, Trimerotropis citrina, M. angustipennis impiger, and M. bivittatus. The order of abundance of the above species changes in some respects as the season develops. M. mexicanus is usually most abundant in the spring, being outnumbered by M. differentialis during the summer.

1. Methods

Small amounts of baits to be compared were placed in paper plates, 6-8 inches in diameter. The plates were placed in a line 10 to 12 feet apart. From 4 to 10 replicates of each bait were used. The same order of baits was kept throughout the line of pans. Uniformity of vegetation and population were sought in placing the plates. Practically all tests were made in alfalfa fields.

The baits were mixed in 1 pound amounts the night previous to the testing. Baits were placed in the pans in the field during the period 5:30 to 6:00 a.m. No pans were replaced with fresh bait during the day. Counts of the number of grasshoppers feeding on the baits were made at 30-minute intervals. Field glasses were used to make the counts. The use of field glasses enabled counts to be made while the observer was at a distance of several feet from the pans. It was found that very few grasshoppers were disturbed while using this method.

Weather conditions records taken were temperature, relative humidity, wind direction, wind velocity, and sky conditions. Temperature and relative humidity were determined by whirling a Fahrenheit psychrometer four feet from the ground. Wind velocity was described as slight, fair, strong, or very strong. Conditions of sky was described as sunny or cloudy, depending upon whether the pans were in the sun or in the shadow of clouds. The above observations were recorded at each 30-minute interval.

2. Number of Grasshoppers Feeding on Various Bran Baits.

Five bran baits of different formulas were compared as to attractiveness by means of pan tests. The formulas of the baits are given below.

A. Bran 100 lbs., water 10-12 gals., white arsenic 4 lbs., molasses 2 gals., amyl acetate 3 ozs.

B. Bran 100 lbs., water 10-12 gals., white arsenic 4 lbs., molasses 2 gals., ground lemons 1 doz.

C. Bran 100 lbs., water 10-12 gals., white arsenic 4 lbs., molasses 2 gals.

D. Bran 100 lbs., lubricating oil (vis. 30) 2 gals., white arsenic 4 lbs.

E. Bran 100 lbs., lubricating oil (vis. 30) 4 gals., white arsenic 4 lbs.

It is noted that in this case all of the baits contained bran and white arsenic.

Table 1.

Number of Grasshoppers Feeding on Various Bran Baits

te	A (Amyl Acetate)	B (Lemon)	C (Water)	D (Oil 2 gals.)	E (Oil 4 gals.)
1-36	181	204	190	168	166
2-36	209	215	193	281	234
2-36	88	76	90	113	94
3-36	55	51	52	41	38
3-36	59	48	56	46	59
otals	592	594	581	649	591
ating	100.0	100.3	98.1	109.6	99.8

Bait A (Amyl Acetate) was chosen as a standard bait for these and all other tests described in this paper. The rating was made on a basis of assigning 100 to the standard bait. While bait D (containing 2 gals. of oil) leads the others in totals there is no significant difference between it and the others.[1] Bait C (containing only bran, white arsenic, water and molasses) is apparently as attractive as the other baits. These data indicate that the addition of

[1] The Fisher Variance Method, as given by Snedecor (80), was used in all data analyzed in this paper.

either amyl acetate or ground lemons to bran-molasses-water baits does not increase their attractiveness for grasshoppers. These results are in agreement with those of Ford (28) and Chamberlin (10). Subsequent plot and cage tests (to be described later in this paper) substantiated these preliminary tests.

3. Comparative attractiveness of Fresh and Day-Old Baits.

Table 2 shows comparative feeding on fresh baits and one-day old baits.

Table 2.

Number of Grasshoppers Feeding on Fresh and Day-Old Baits.

Date	Fresh Amyl Acetate	Old Amyl Acetate	Fresh Lemon	Old Lemon
6-9-36	131	83	126	98
6-10-36	123	87	108	80
6-10-36	58	35	52	30
Totals	312	205	286	208
Ratings	100.0	65.6	91.6	66.6

There is no significant difference between the two fresh baits nor between the two old baits. There is, however, a highly significant difference between the fresh baits and day-old baits. The day-old baits were only 68.9 per cent as attractive as the fresh baits.

4. Comparative Attractiveness of Bran and Sawdust Baits.

A series of 4 baits consisting of all bran, all old sawdust, one-half bran - one-half old sawdust, and one-half bran - one-half new sawdust were compared as to attractiveness. The sawdust, both old and new, was from pine. All baits contained amyl acetate, molasses, white arsenic and water.

Table 3.

Number of Grasshoppers Feeding on Bran and Sawdust Baits

Date	All Bran	All Old Sawdust	½ Bran ½ Old Sawdust	½ Bran ½ New Sawdust
6-24-36	68	40	65	76
6-25-36	85	25	49	79
6-27-36	88	37	88	78
Totals	241	102	202	233
Ratings	100.0	42.3	83.8	96.6

Although the amount of data presented in Table 3 is very small it is obvious that bran is distinctly more attractive than pure sawdust. Analysis of the data indicates the difference is highly significant. Subsequent pan and plot tests verified these results. The addition of 50 per cent bran caused a distinct increase in attractiveness. There appears to be no difference between old and new sawdust.

5. Comparative Attractiveness of Various Baits.

During June, July and August of 1937, the following baits were compared in a series of 15 pan tests. The formulas of the baits tested are given below:

No. 1 - Bran 100 lbs., molasses 2 gals., amyl acetate 3 ozs., sodium arsenite 2 qts., water 10 gals.

No. 2 - Bran 100 lbs., sodium arsenite 2 qts., water 12 gals.

No. 3 - Bran 50 lbs., sawdust 50 lbs., sodium arsenite 2 qts., water 10-12 gals.

No. 4 - Bran 100 lbs., white arsenic 4 lbs., lubricating oil (vis. 30) 2 gals.

No. 5 - Cottonseed hulls (bran) 100 lbs., sawdust 50 lbs., sodium arsenite 2 qts., water 10 to 12 gals.

No. 6 - Cottonseed hulls (ground) 50 lbs., sawdust 50 lbs., sodium arsenite 2 qts., water 10 to 12 gals.

No. 7 - Cottonseed hulls (ground) 100 lbs., sodium arsenite 2 qts., water 10 to 12 gals.

No. 8 - Cottonseed hulls (ground) 50 lbs., alfalfa meal 50 lbs., sodium arsenite 2 qts., water 10 to 12 gals.

No. 9 - Sawdust 50 lbs., alfalfa meal 50 lbs., sodium arsenite 2 qts., water 10 to 12 gals.

Table 4 shows the comparative attractiveness of these 9 baits.

Table 4.

Number of Grasshoppers Feeding on Various Baits, 1937

Baits Replications	1	2	3	4	5	6	7	8	9
6-5-37	352	306	298	174	163	282	335	323	256
6-9-37	152	219	252	329	172	159	145	231	182
6-11-37	240	186	127	239	140	274	155	147	232
6-12-37	344	340	258	382	234	240	263	321	313
6-14-37	118	106	108	115	45	62	57	85	79
6-17-37	192	204	152	227	205	176	191	244	268
6-18-37	72	71	73	100	30	53	26	71	54
6-19-37	78	50	59	85	34	28	18	52	42
6-26-37	32	24	17	32	8	10	8	17	19
7-1-37	44	18	11	19	8	7	15	16	4
7-9-37	49	62	51	55	12	12	17	21	24
7-13-37	13	4	5	8	3	1	1	7	10
7-16-37	15	10	11	12	7	2	2	8	2
7-18-37	19	11	6	2	4	7	8	9	4
7-23-37	9	4	6	7	3	3	8	4	9
Total	1729	1615	1434	1786	1068	1316	1249	1556	1498
Rating[2]	100.0	93.4	82.8	103.3	61.7	76.1	72.2	90.0	86.6

Bait No. 1 (A in Table 1) was used as the standard. There is no significant difference between Nos. 1, 2, and 4. There is, however, a significant difference between these

[2] This rating is made on a basis of assigning 100 to the standard bait (No. 1).

and the other 6 baits. Bait No. 5 (Cottonseed bran) ranked last, being only 61.7 per cent as attractive as the standard bait (No. 1). No. 8 (Alfalfa meal-cottonseed hulls) and No. 9 (alfalfa meal-sawdust) rated 90 per cent and 86. 6 per cent, respectively, as attractive as the standard. It is interesting to note that No. 1 (A) and No. 4 (D) have the same order of rating in both Tables 1 and 4. Bait No. 10 (millrun bran 25 lbs., sawdust 75 lbs., sodium arsenite 2 qts., water 10-12 gals.) was added to the list of baits on June 26, 1937. Table 4a is presented for the purpose of showing the comparative attractiveness of baits No. 1 and No. 10.

Table 4a

Number of Grasshoppers Feeding on Baits 1 and 10

its plication	No. 1	No. 10	Replication	No. 1	No. 10	Replication	No. 1	No. 10
6-26-37	32	25	7-18-37	19	15	8-19-37	4	5
7-1-37	44	36	7-23-37	9	5	8-25-37	63	49
7-9-37	49	33	8-14-37	68	45	8-27-37	32	22
7-13-37	13	3	8-16-37	141	112	Totals	494	362
7-16-37	15	11	8-18-37	5	1	Rating	100.0	73.3

If No. 10 were rated with the other 9 baits given in Table 4, it would occupy 8th place.

6. Number of Grasshopper Feeding at Various Periods.

Seventeen pan tests were made, each beginning at 6:00 a.m. and continuing until 12:00 a.m. The results, given in Table 5 and Figure 2, show total feeding on all baits by

30-minute periods. With the exception of a few cool days in the spring, feeding on pans in the afternoon was generally very light. The maximum feeding period occurred sometime in the forenoon in each of the 17 tests given in Table 5. Therefore, it was not thought necessary to include afternoon feeding records of the tests in Table 5.

In all of these tests, made under varying conditions, the maximum feeding period was never earlier than 7:30 a.m. nor later than 11:30 a.m. Ten of the seventeen maximum feeding periods (Table 5) were between 8:00 and 9:30 a.m. The maximum feeding period occurred 5 times at 9:00, 3 times at 8:00, 3 times at 11:00, twice at 9:30, once at 8:30, once at 10:30, once at 7:30, and once at 11:30.

Figure 1 shows the maximum feeding periods of 24 tests made during 1936 and 1937. These 24 tests include the 17 tests given in Table 5 in addition to 7 others. These 7 tests were not included in Table 5 because they were not begun each day until after 6:30 a.m. Little change in the distribution of maximum feeding periods over the forenoon is produced by including these additional 7 tests. Sixteen of the 24 feeding peaks occurred between 8:00 and 9:30 a.m.

On the basis of total feeding, shown in Table 5, figure 2, 54 per cent of all feeding occurred between 8:00 and 10:00 a.m. Of the remaining 46 per cent, 14 per cent occurred in the period 6:00 to 8:00 a.m. and 32 per cent between 10:00 and 12:00 a.m. The greatest number of grasshoppers feeding were recorded at 9:00 a.m. These data indicate that there is considerable variation in the time of day that maximum feeding occurs, although the peak is usually reached sometime in the forenoon.

7. The Influence of Temperature on Bait Feeding.

Figure 1 shows the temperature of the above mentioned 24 maximum feeding periods. It is indicated by Table 5 and Figure 1 that the time at which peak feeding occurs is influenced by temperature. The temperature of a maximum feeding period never exceeded 89 degrees nor was less than 70 degrees. The mean temperature for the 24 maximum feeding periods was 80.2 degrees.

Figure 2 shows the total feeding, by periods, of the 17 tests given in Table 5. According to this, grasshoppers fed very little at temperatures below 70 degrees, most actively at 75 to 80 degrees, and declined above 80 degrees. Practically no feeding was observed above 90 degrees. This range of feeding temperatures is slightly higher than those found by Parker (63) in Montana and Langford (44) in Colorado. This difference is probably due to the fact that some of the tests run in August and the latter part of July were made during hot days when the temperatures at 6:00 a.m. were 72 degrees or above. In other words, the lower range of feeding temperature was not present in some of the tests. This fact would tend to raise the mean temperatures.

A more nearly accurate view of the temperatures of maximum feeding is shown in A, B, C, D, and E of Figure 3. These graphs show 5 consecutive tests which were run during the period June 5th to June 17th. In these tests the greatest feeding occurred at temperatures of 70, 73, 75, 77, and 81 degrees. The mean temperature of these maximum feeding periods is 75.2 degrees.

By a study of Table 5 and Figure 3 it is seen that there is a considerable decrease in total feeding on baits in pans as the season advances. Checking on the temperatures for those days where little feeding was done, it is found that they are relatively high. It was found that where the mean temperature for the period from 6:00 to 12:00 a.m. was much above 80 degrees, the total feeding on pans for the morning was very slight. F, G, H, I, and J of Figure 3 illustrate cases where the mean temperature was considerably above 80 degrees. A, B, C, D and E are examples of days where the mean morning temperatures were about 80 degrees or below. The above data seem to indicate that poor kills with baits would result on days with high mean temperatures. This would seem to be especially true if the temperatures at spreading time were above the optimum range. The extent to which this affected the percent mortality of control tests will be discussed later.

8. The Relation of Some Other Factors to Bait Feeding.

So far as is known, the influence of relative humidity on bait feeding has not been definitely established. Some information regarding the relation of relative humidity and sunshine to feeding on baits is shown in Figure 3. It is noted in all of the graphs that the relative humidity decreased as the temperature increased. This is due, of course, to the increased water holding capacity of the warmer air. Until the optimum temperature is reached the

Table 5. Maximum and Total Feeding on Pans by Periods

Date	6:00 T H	6:30 T H	7:00 T H	7:30 T H	8:00 T H	8:30 T H	9:00 T H	9:30 T H	10:00 T H	10:30 T H	11:00 T H	11:30 T H	12:00 T H
6-16-36	4 s 76	13 s 78	78 s 84	103 s 86	(129) s 89	118 s 90	105 s 90	98 s 90	86 s 90	55 s 90	45 s 90	32 s 91	24 s 91
6-23-36	5 c 68	12 c 69	28 c 71	23 c 72	48 c 74	61 c 76	(68) c 76	66 c 77	63 c 82	50 c 83	48 c 84	35 s 85	25 s 86
6- 5-37	13 c 62 90	26 c 64 90	50 s 62 94	93 s 64 90	97 c 65 90	128 s 66 90	106 s 68 85	149 s 68 85	127 c 68 85	138 s 70 90	(162) c 70 77	141 c 70 77	120 c 71 81
6- 9-37	16 s 64 92	16 c 65 92	20 c 68 90	38 c 70 90	72 c 71 86	87 c 74 82	70 c 73 78	79 c 73 74	61 c 71 82	47 c 70 86	102 c 73 78	(118) c 73 74	113 c 74 86
6-11-37		5 c 64 100	8 c 65 100	6 c 64 100	20 c 65 90	74 c 67 85	68 c 66 95	94 c 68 85	107 c 71 82	(150) c 74 82	136 c 75 74	74 c 75 74	87 c 82 63
6-12-37		49 s 70 90	67 c 70 90	80 c 71 82	130 s 72 86	205 s 75 74	(302) s 77 75	296 s 78 75	232 s 79 72	273 s 82 68	171 s 83 70	155 s 85 66	150 s 86 64
6-14-37		9 c 73 78	22 c 76 83	25 c 76 83	19 c 77 75	19 c 75 91	30 c 74 91	66 c 78 79	83 c 81 79	107 s 83 63	(112) s 83 66	66 c 85 63	40 c 86 60
6-17-37		26 s 75 91	36 s 77 83	71 s 78 83	183 s 80 79	223 s 80 79	(234) s 81 79	173 s 82 76	132 s 86 74	95 c 86 74	64 c 89 67	72 c 89 60	48 c 89 67
6-18-37		9 s 77 83	12 s 78 87	39 s 82 73	51 s 83 73	47 s 86 70	(53) s 87 64	47 s 89 64	26 s 90 65	28 s 91 62	18 s 92 62	16 s 92 62	21 s 93 60
6-19-37		10 s 75 91	24 s 77 86	53 s 79 83	67 s 81 75	(88) s 82 72	79 s 85 63	52 s 86 63	24 s 89 58	16 s 90 58	12 s 91 58	9 s 92 59	7 s 93 59

Legend: Number of 'hoppers feeding is underlined; temperature in lower left; relative humidity in lower right; numbers in parentheses indicate maximum feeding period for the day; letters indicate sunny or cloudy.

Table 5. Maximum and Total Feeding on Pans by Periods (continued)

Date	6:00 T H	6:30 T H	7:00 T H	7:30 T H	8:00 T H	8:30 T H	9:00 T H	9:30 T H	10:00 T H	10:30 T H	11:00 T H	11:30 T H	12:00 T H
6-26-37:		11 s 80 72	24 s 83 62	(29) s 85 59	26 s 87 57	27 s 88 55	22 s 90 52	13 s 93 47	28 s 93 47	1 s 96 44	1 s 97 44	0 s 98 41	0 s 99 37
7- 9-37:		11 s 78 64	22 s 79 64	36 c 80 64	(68) s 83 54	58 s 84 57	58 s 86 50	25 s 88 57	19 s 91 44	8 s 91 44	0 s 93 44	0 s 94 42	0 s 96 38
8-16-37:	49 c 74 86	63 c 75 78	84 c 76 74	87 c 77 75	(91) c 79 72	81 c 79 79	61 c 79 79	55 c 84 66	35 c 86 63	43 c 87 63	48 c 85 66	35 c 85 62	21 c 86 60
8-18-37:		0 c 68 95	4 c 70 95	42 s 71 95	68 s 77 83	94 s 79 75	96 s 81 72	(99) s 82 72	71 s 87 63	63 s 86 63	45 s 89 58	32 s 90 29	24 s 89 58
8-19-37:	11 c 72 90	22 c 73 86	19 c 74 81	19 c 72 95	33 c 79 68	23 c 79 72	13 c 77 71	12 c 78 71	12 c 80 72	21 c 81 72	(38) c 83 69	20 c 85 63	14 c 86 60
8-25-37:	1 c 74 90	2 c 74 90	6 c 75 91	12 c 76 86	18 c 77 86	25 s 78 83	28 s 80 75	(34) s 83 75	23 s 85 70	20 s 86 66	8 s 88 64	4 s 90 60	1 s 92 56
8-27-37:	7 c 74 86	6 c 75 82	7 c 76 82	7 c 77 78	10 c 77 78	7 c 77 82	(16) c 82 76	14 c 85 66	13 s 87 66	8 s 89 65	1 s 91 61	0 s 92 60	1 s 93 58
Totals	90	290	511	763	1130	1365	1409	1372	1142	1123	1009	909	696

Legend: Number of 'hoppers feeding is underlined; temperature in lower left; relative humidity in lower right; numbers in parentheses indicate maximum feeding period for the day; letters indicate sunny or cloudy.

feeding varies inversely with the relative humidity. After this point is reached, feeding varies directly with relative humidity. The relative humidity of the maximum feeding periods was usually between 70 and 80 per cent. Since the relative humidity is so closely influenced by the temperature, it is believed that this apparent correlation of the relative humidity with feeding is but a result of the more direct correlation of temperature with feeding.

The rate of feeding, apparently, is not affected by cloudy skies, the temperature being the influential factor. The sky was cloudy and the sun overcast during seven (41.1 per cent) of the seventeen maximum feeding periods shown in Table 5. In ninety-nine (46.7 per cent) of the total 212 feeding periods, given in Table 5, the sky was recorded as being cloudy. Thus it is noted that there is little difference between the percent of maximum feeding periods that were cloudy and of the percent of all feeding periods that were cloudy.

The direction and velocity of wind, as recorded in these tests, do not seem to affect feeding on baits. It might be said that no high velocities for wind were recorded.

9. Relation of Pan Test Results to the Control of Grasshoppers.

These pan test results indicate that bait should not be spread at certain specified hours. Even though peak feeding in Oklahoma usually occurs in the forenoon, there is a great deal of variation in the time of day when maximum feeding occurs. Peak feeding is much more closely correlated with a certain range of temperature (70-80 degrees). Therefore, bait should be spread when the temperature is not lower than 68 degrees nor higher than 82 degrees. This is the time when grasshopper activity is confined to the ground surface.

There is evidence to indicate that it is advisable to poison grasshoppers early in the season. Under ordinary Oklahoma conditions after the middle of June the daily period of optimum temperatures (70 to 80 degrees) is relatively short. This fact would seem to decrease the percentage of mortality of bait control measures. In addition to this, Langford (44) has pointed out that adult 'hoppers eat almost 100 times as much as first instar nymphs. Furthermore, nymphs are generally concentrated in smaller areas where they can be poisoned with the expenditure of less time and money.

B. Comparative Efficiency and Costs of Baits as Shown by Plot Tests, 1936.

1. Methods.

During the period from July 1 to August 26, 1936, plot tests were run in the field to compare the effectiveness of 13 baits. Baits were broadcast by hand in one-half and in one acre plots, at the rate of 15 lbs. (dry weight) per acre. The number of baits used in a single test never exceeded the number that could be spread in a period of 45 minutes. Spreading was begun in every test at 6:00 a.m. Bait No. 1 (formula on p. 19) was chosen as a standard by which to compare other baits. The standard bait was spread in all tests made. The order in which the baits were spread was rotated through the series, thus equalizing the time element in feeding. Special efforts were made to select plots of uniform population and vegetation. The same weather conditions as previously described (p. 19) were recorded.

Previous to the staking off of plots, the field was carefully surveyed with the above considerations in mind. The grasshopper population was estimated, using the method suggested by Shotwell (77) in making grasshopper surveys. By this method, the number of grasshoppers per square yard was estimated while walking through the field at a uniform pace. A modification of this was to count the number of grasshoppers at rest on one square foot. It was found that ratings made by different observers agreed in a great majority of cases. Table 6 shows Shotwell's Rating of Infestation.

Table 6.

Shotwell's Rating of Grasshopper Infestation

Rating		No. of "hoppers" per square yard	
		In Fields	Field Margins and Roadsides
Normal	1	1.0	4
Light	1.5	1.5	6
Moderate	2	2.0	8
	2.5	3.0	12
Heavy	3	4.0	16
	3.5	6.0	24
Very Heavy	4	8.0	32
	4.5	12.0	48
	5	16.0	64

The per cent of mortality was estimated by two methods. First, the original estimated population was compared with the population of the third day after poisoning. Second, the number of dead grasshoppers per square yard was compared with the number per square yard of the original population. An average of these two figures was taken as the mean mortality for a plot. To illustrate: if the per cent mortality as estimated by the first method was 70 and that by the second was 80, the mean of the two or 75, would be recorded as the per cent mortality for the test.

Plot tests were run in alfalfa and cotton fields. A square frame, one square yard in area, was used for making counts of dead grasshoppers in the alfalfa fields. These counts, ten in number, were taken at random in the central part of the plot. In cotton fields, counts were made in a space ten feet long including one row and one-half of the middle on each side. Ten such spaces were counted from each plot. The mean of the ten counts made in each plot was taken as the average number of dead grasshoppers per square yard for the plot.

Occasionally, drifting of the poisoned grasshoppers to near-by trees occurred. In these cases the data were discarded. Very little intra-field migration was noticed. This was probable held down by selection of fields of uniform vegetation. A few tests were eliminated because of migration from near-by grain fields, which had been cut.

The formulas of the baits tested are given below.

1. Bran 100 lbs., molasses 2 gals., amyl acetate 3 ozs., sodium arsenite 2 qts., water 10-12 gals.

2. Bran 100 lbs., sodium arsenite 2 qts., water 10-12 gals.

23. Bran 100 lbs., molasses 2 gals., sodium arsenite 2 qts., water 10-12 gals.

3. Bran 50 lbs., sawdust 50 lbs., sodium arsenite 2 qts., water 10-12 gals.

4. Bran 100 lbs., sodium arsenite 2 qts., oil (vis. 30) 2 gals.

15. Bran 50 lbs., cottonseed hulls 50 lbs., sodium arsenite 2 qts., water 10-12 gals.

13. Cottonseed hulls 75 lbs., shorts 20 lbs., molasses 1 gal., sodium arsenite 2 qts., water 10-12 gals.

16. Sawdust 85 lbs., flour 15 lbs., sodium arsenite 2 qts., water 10-12 gals.

17. Bran 50 lbs., cane pulp 50 lbs., sodium arsenite 2 qts., water 10-12 gals.

21. Cottonseed hulls 100 lbs., sodium arsenite 2 qts., water 10-12 gals.

14. Sawdust 100 lbs., sodium arsenite 2 qts., water 10-12 gals.

18. Cane pulp 100 lbs., sodium arsenite 8 qts., water 10-12 gals.

20. Commercial bait[3] consisting largely of rice hulls, molasses and poison.

As shown in the formulas, sodium arsenite (4 lbs. A_2O_3 per gal.) was used as the poison in all baits of this series. Its effectiveness has been established by many workers and with water baits it mixes more quickly and evenly than white arsenic. The data of these plot tests are summarized in Tables 7 and 8.

2. Costs of Baits.

The cost of using a bait is incurred in two ways. There is the time and labor spent in mixing and spreading the bait and the cost of the materials composing it. One man-hour of labor is allowed for mixing 100 lbs. of bait. Some of the baits mixed more quickly and easily than others, but, in general, the allowance was fairly accurate. One man-hour and one team-hour of labor, as suggested by Parker (64), were allowed for spreading 100 lbs. of bait. The

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[3] This bait was tested because a local mill had prepared and sold considerable amounts of it.

wages (20 cents per hour for a man and 30 cents per hour for a man and team) were based on farm-labor survey data collected by the Agricultural Economics Department of Oklahoma Agricultural and Mechanical College.

In determining the cost of materials, the prices used were based on the average prices paid by consumers in Stillwater, Oklahoma since 1930, when buying relatively small amounts at retail prices. In the case of sawdust, only the hauling expense of $4.00 per ton was allowed. A price of $12.00 per ton was allowed for cottonseed hulls. The costs of sawdust baits, as given in Table 7, will be too low for those sections of the state where shipping for a considerable distance is necessary. On the other hand, the costs of cottonseed baits, as given, will be too high for the section that has an abundant supply of hulls near at hand. These changes in the relative costs of sawdust and cottonseed baits must be made when recommending baits for the southwestern part of the state. To illustrate, the cost of sawdust in Kiowa and adjacent counties in 1938 was $12.00 per ton. Due to local mills having a large supply of cottonseed hulls on hand, and being interested in protecting the cotton crop for this section, these concerns sold hulls to the mixing stations at a rate of $5.00 to $7.00 per ton. The prices used on other materials were as follows: bran $1.00 per 100 lbs., blackstrap molasses 25 cents per gal., amyl acetate 7 cents per oz., sodium arsenite 30 cents per gal., shorts $1.50 per 100 lbs., flour $2.75 per 100 lbs., cane pulp 50 cents per 100 lbs., rice hulls 50 cents per

100 lbs., lubricating oil 25 cents per gal., alfalfa leaf meal $1.80 per 100 lbs., mill-run bran $1.00 per 100 lbs., cottonseed bran 60 cents per 100 lbs.

Column 6 (Table 7) gives the per acre cost of using the various baits at a rate of 15 lbs. (dry weight) per acre. Column 7 shows the cost per acre to obtain control of a light population (4 'hoppers per sq. yd.) of grasshoppers. The word control often varies in its meaning, depending upon who is using it. To a person working with baits for the first time control may mean keeping his crop from being completely destroyed. To the theorist it may mean a mortality rate of 100 per cent. According to Shotwell (77), a grasshopper population above 2 grasshoppers per square yard (over a field) should be treated with control measures. Control, as used in this paper, will mean the reduction of the population to two or less grasshoppers per square yard. It is understood, by the writer, that any set cost for controlling a given population of grasshoppers will be somewhat ambiguous. The cost given in columns 7, 8, and 9 are submitted merely as relative estimates. The aim, in these columns, is to show how the two factors of initial cost and efficiency work together to determine the relative costs of using the baits under varying populations. A factor, not considered here, is the damage that might be done to crops while respreading several times.

To illustrate how the costs in columns 7, 8, and 9 are estimated let us consider bait No. 2. The cost of spreading 15 lbs. (dry weight) of this bait over one acre is 25 cents (column 6). The mean per cent mortality is 74.0. Multiplying 8 (No. of 'hoppers per sq. yd.) by .74, equals 5.92 ('hoppers per sq. yd. killed). Subtracting 5.92 from 8 we find that the remainder is 2.08. This indicates that the population has been reduced to practically two grasshoppers per square yard, thus obtaining control. Therefore, the cost of getting control per acre of a heavy population with bait No. 2 is 25 cents, the cost of one spreading. In the case of bait No. 18 the mean mortality was 45 per cent. The cost of spreading one acre one time is 17 cents. Multiplying 8 by .45 equals 3.6. Subtracting 3.6 from 8 equals 4.4. It is noted that the number 4.4 ('hoppers per sq. yd. remaining) is too high to consider control as having been obtained. A second spreading of the bait will be necessary. Multiplying 4.4 by .45 (mean per cent mortality) equals 1.98 ('hoppers per sq. yd. killed). Subtracting 1.98 from 4.40 equals 2.42 ('hoppers per sq. yd. left alive) This average number of 2.42 grasshoppers per square yard is slightly high to consider control as being completely obtained. The cost of two spreadings with No. 18 has cost 34 cents and a third spreading may be necessary. If the bait is spread the third time the total cost will be 51 cents.

3. Rating of Baits.

The rating in effectiveness was made by assigning a rating of 100 to the check (No. 1, standard bait) plots, and comparing the percentage of control of the adjoining test

Table 7. Comparative Effectiveness and Costs of Baits, 1936.

Bait No.	Number of Tests	Mean Per Cent Mortality	Mean Per Cent Mortality of Standard	Rating Compared to No. 1 as Standard	Cost Per Acre for one Spreading Cost	Number of Spreadings and Costs Per Acre to get Control of Various Populations. Light Population 4 'hoppers Per sq. yd.	Heavy Population 8 'hoppers Per sq. yd.	Very Heavy Population 16 'hoppers Per sq. yd.
1	52	71.5		100.0	35	1-35	1-35	2-70
2	9	74.0	75.0	98.6	25	1-25	1-25	2-50
23	9	74.0	75.0	98.6	32	1-32	1-32	2-64
3	11	68.0	71.1	95.7	19	1-19	1-19	2-38
*4	3	70.0	75.0	93.3	32	1-32	1-32	2-64
15	13	61.0	67.0	91.0	22	1-22	2-44	3-66
13	11	66.0	73.0	90.4	25	1-25	2-50	3-75
16	9	64.0	73.0	87.6	19	1-19	2-38	3-57
17	4	58.0	70.6	82.1	21	1-21	2-42	3-63
21	10	48.0	67.0	71.6	19	2-38	2-38	4-76
14	11	48.0	71.0	67.6	13	2-26	2-26	4-52
18	4	45.0	70.1	64.2	17	2-34	3-51	4-68
**20	2	25.0	55.0	45.4	33	3-99	5-132	8-264

*13 subsequent tests rated this bait up with the standard.

**This was tested because a local mill had prepared and sold considerable amounts of it.

plots with that of the check. For instance, in bait No. 2 the average control was 74 per cent while adjoining standard plots averaged 75 per cent control. Since 74 is 98.6 per cent of 75, the rating in effectiveness of bait No. 2 is 98.6. The apparent discrepances between columns 3, 4, and 5 (Table 7) can be explained by pointing out that not all of these tests were made at the same time nor under the same conditions. Column 4, which gives the average percent control of the standard check (No. 1) bait plots, was compared with column 3 to give column 5. This column gives rating on a basis of 100 for the standard bait. It is interesting to note that the standard mixture (No. 1) gave the best kill of all baits tried. However, the efficiency of No. 2 bait so nearly equalled that of the standard, that it would not seem advisable to incur the additional expense of adding amyl acetate and molasses.[4] By adding these the price was increased 25.7 per cent while the efficiency was increased only 1.4 per cent.

The bran-sawdust mixture (No. 3) was 95.7 per cent as efficient as the standard, and its cost was but 59.4 per cent as great. It should be noted that its costs for controlling heavy and very heavy populations (columns 8 and 9) are the lowest for all 13 baits. Considering these facts, it appears that the bran-sawdust bait (No. 3) was the most satisfactory one tested in this series. In this connection it might be stated that the major portion of the 2,000

[4] Cage and pan tests conducted in 1937 showed no significant difference between Nos. 2 and 4 and the standard.

tons of bait used in Oklahoma in the summer of 1936, and later in 1937, was this particular mixture. It was reported, on the whole, as giving very satisfactory results.

The baits containing cottonseed hulls (No. 15, 13, and 21) are of special interest to this section where considerable cotton is grown. It was thought, after making these tests, that grinding of the hulls would make the baits more easily handled by grasshoppers, thus increasing their efficiency. Ten cage tests, made in 1937, indicated that grinding does not increase their efficiency. The use of cottonseed hulls would seem to depend upon the comparative prices of hulls, sawdust, and other cheap filler materials. As stated on p. 34, the cost of the cottonseed baits, shown in Table 7, were based on retail prices in Stillwater over a period of years. If, as stated before, the costs are estimated on the basis of the respective prices of cottonseed hulls and sawdust in southwestern Oklahoma in 1938, the results would indicate recommendation of cottonseed hull baits. Under these conditions the costs of bait No. 15 (Table 7) would change from 22 to 19 cents; that of No. 13 from 25 to 20 cents; and, that of No. 21 from 19 to 14 cents. On the other hand, the costs of the sawdust would be raised correspondingly. The cost of No.3 would increase from 19 to 22 cents; that of No. 16 from 19 to 23 cents; and that of No. 14 from 13 to 19 cents.

The sawdust-flour mixture (No. 16) rated well in the series. If flour could be bought in large quantities at a lower price, it would be practical to use. Although the number of tests on rice hulls and cane pulp (Nos. 18, 19, and 20) was too small to permit drawing of conclusions, it was believed they did not show sufficient promise to justify further trials. The commercial bait (No. 20) gave the poorest results of any of the baits tried and should not be recommended under any circumstances.

The pure sawdust bait (No. 21) was only 71.6 per cent as effective as the standard. When available at the low cost of 13 cents per acre it would be practical under moderate infestations and dry weather conditions.

4. Relation of Temperature to Plot Test Results.

Table 8 shows the results of 50 tests on Bait No. 1 arranged according to temperatures at spreading time. The temperatures given are those taken at 6:00 a.m. on the days when tests were made. The 50 days, on which this bait was spread, were grouped into six divisions according to their temperatures at 6:00 a.m.

In a previous paragraph it was pointed out that temperatures above 80 degrees caused a decided decrease in total feeding on baits in pans. It was suggested that if at the time of spreading, the temperature was above the optimum range, and did not again reach this range during the day, the per cent mortality resulting would be low. No conclusive evidence was obtained on this problem. While there is a small difference between column 4 and the others, in Table 8, it is not significant. Since these tests were run over a period of three days, it is not definitely known just at what time in this period grasshoppers were poisoned. In other words, a certain percent of the mortality of these tests may have been due to feeding that occurred several hours after temperatures than those recorded in Table 8. Therefore, these are not reliable results upon percent mortality obtained at high temperatures.

Table 8.

Results of Tests on Bait No. 1 Arranged According to Temperatures at Spreading Time.

Temperatures	61-65	66-70	71-75	76-80	81-85	86-90
	60	75	60	65	60	60
		70	60	80	50	80
		40	70	90	75	75
			70	60	65	70
			75	70	80	
			75	70	70	
			75	75	70	
			75	80	75	
			75	80	75	
				75	80	
				70	75	
				75		
				80		
				75		
				75		
				80		
				75		
				75		
				70		
				75		
				70		
Mean Per Cent						
Mortality	60.0	61.7	70.6	74.5	70.8	71.2

C. Comparative Efficiency and Costs of Baits as Shown by Cage Tests, 1937.

1. Methods.

During the summer of 1937 cage tests were substituted for the plot tests used in 1936. The method used with certain modifications, was the one devised by Ford and Larrimer (29). The cages were of a square screened type, one cubic foot in volume. Plots of alfalfa one-half acre to one acre in size were used. Uniformity in grasshopper population and vegetation were sought. Baits were spread by 6:00 a.m.

Three hours after spreading the plots were swept with a hand net. The time of sweeping of all plots never exceeded 45 minutes. The order of spreading and sweeping of baits was rotated through the series. From 100 to 200 grasshoppers were caught from each plot and placed in two cages, from 50 to 100 being put in each. Two cages, of 50 to 100 grasshoppers each, were caught from unpoisoned plots to act as checks.

The cages of grasshoppers were hauled to the station campus where they were placed under trees in such a position that they were in the sun in early morning and late afternoon and in the shade the rest of the day. Once each day fresh green food, in a small bottle containing water, was placed in each cage. At the end of 60 hours, counts were made of the dead and living grasshoppers. The few that were in a weakened condition were counted as dead if after being placed on their sides they did not immediately regain an upright position. The per cent mortality was determined by dividing the number of dead 'hoppers by the total number in the cage.

2. Presentation of Data

Twelve baits were compared as to effectiveness and costs by means of cage tests. In addition to baits Nos. 1 to 9 (given on p. 22 and 23) three others were tested. The formulas of these baits are given below.

No. 10. Millrun bran 25 lbs., sawdust 75 lbs., sodium arsenite 2 qts., water 10-12 gals.

No. 11. Millrun bran 25 lbs., sawdust 75 lbs., molasses 2 gals., amyl acetate 3 ozs., sodium arsenite 2 qts., water 10-12 gals.

No. 12. Millrun bran 25 lbs., sawdust 75 lbs., white arsenic (As_2O_3) 4 lbs., lubricating oil 2 gals.

The number of replications for each bait varied from ten to forty-two. All baits were not spread each day, only four to six generally being put out. Since conditions varied from one day to the next, it would not be accurate to compare baits where tests were run at different times. All baits are compared with the standard bait (No. 1). In analyzing the results the Fisher Variance Method, as given by Snedecor (80), was used. Table 9 shows the analysis of variance of all baits. The general difference between baits is highly significant. If the freedom is not starred the difference is not significant.

Table 9.

Analysis of Variance of All Baits.

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	Freedom
Total	206	35,194.22		
Between Bait Means	11	29,980.67	2,725.51	
Between tests of same Bait	195	5,613.55	28.78	94.70**

** Highly Significant (100 to 1)

Table 10

Analysis of Variance

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	Freedom
Baits No. 1 and No. 2				
Total	23	517.33		
Between Bait Means	1	16.50	16.50	
Between Tests of Same Bait	22	500.83	22.77	0.73
Mean No. 1 - 65.5		No. 2 - 63.8	Check - 8.1	
Baits No. 1 and No. 3				
	22	843.42		
	1	404.37	404.37	
	21	439.05	20.91	19.34**
Mean No. 1 - 67.3		No. 3 - 58.9	Check - 7.0	
Baits No. 1 and No. 4				
	30	724.30		

** Highly Significant

Analysis of Variance (continued)

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	Freedom
Between Bait Means	1	40.86	40.86	
Between Tests of Same Bait	29	683.44	23.5	1.73
Mean No. 1-66.3	No. 4 - 64.0	Check- 7.1		
Baits No. 1 and No. 5				
Total	17	10,142.62		
Between Bait Means	1	9,952.98	9,952.98	
Between Tests of Same Bait	16	189.64	11.85	839.91**
Mean No. 1- 65.2	No. 5- 17.9	Check- 7.9		
Baits No. 1 and No. 6				
	25	2,595.16		
	1	2,205.20	2,205.20	
	24	389.96	16.24	135.78**
Mean No. 1- 67.1	No. 6-49.5	Check- 7.8		
Baits No. 1 and No. 7				
	20	3,107.31		
	1	2,848.81	2,848.81	
	19	258.50	13.60	209.47**
Mean No. 1- 66.0	No. 7-42.7	Check - 8.0		
Baits No. 1 and No. 8				
	24	1,941.89		
	1	1,560.40	1,560.40	
	23	381.49	16.58	94.11**
Mean No. 1- 67.6	No. 8 -51.8	Check- 7.7		

Analysis of Variance (continued)

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	Freedom
Baits No. 1 and No. 9				
Total	23	5,064.43		
Between Bait Means	1	4,483.18	4,483.18	
Between Tests of Same Bait	22	581.25	26.42	169.68**
Mean No. 1- 66.4 No. 9- 39.0 Check- 6.7				
Baits No. 1 and No. 10				
	69	5,852.55		
	1	3,365.41	3,365.41	
	68	2,487.14	36.57	92.02**
Mean No. 1- 66.8 No. 10- 52.9 Check- 7.3				
Baits No. 1 and No. 11				
	33	1,680.63		
	1	1,050.63	1,050.63	
	32	630.00	19.68	53.38**
Mean No. 1- 66.4 No. 11- 55.3 Check- 7.7				
Baits No. 1 and No. 12				
	19	1,583.42		
	1	1,259.69	1,259.69	
	18	323.73	17.98	70.06**
Mean No. 1- 66.1 No. 12- 50.0 Check-7.1				

** Highly Significant

As in the tests made in 1936, the standard Bait (No. 1) gave the highest per cent mortality of all baits. It will be noted, however, in Table 10, that there was no significant difference between No. 1 and No. 2 nor between No. 1 and No. 4. This would indicate that the extra cost of adding molasses and amyl acetate to bran baits would not be advisable. No. 3 (one-half bran and one-half sawdust) again proved to be one of the most practical baits, considering both effectiveness and expense. As shown in Table 11 and Figure 5 it was 87. 5 per cent as effective as the standard while costing only 59. 4 per cent as much.

No. 4 (bran - oil), as stated above, was equally good as the standard on the basis of first day feeding. To compare the relative lasting effectiveness of oil and water baits, a test was run over a period of five days. No. 1 and No. 4 were spread on five acre plots. The plots were swept at 9:00 a.m. each day. The results by days are given in Table 12 and Figure 4. After the second day the results indicate that the oil bait was definitely more effective. Over the entire five-day period the oil bait was 31. 7 per cent more effective than No. 1, the water bait. This may be due to the slower rate of evaporation of the oil as compared with the water. While these few records are interesting, the problem should be given a more extended investigation before final conclusions can be made.

Table 11. Comparative Effectiveness and Costs of Baits, 1937.

Bait No.	Number of Tests	Number of 'hoppers Included in Tests	Mean Per Cent Mortality	Mean Per Cent Mortality of Standard	Mean Per Cent Mortality of Check Plots	Rating Compared to No. 1 as Standard	Cost Per Acre for one Spreading Cents	Number of Spreadings and Costs Per Acre to get Control of Various Populations: Light Population 4 'hoppers Per sq. yd.	Heavy Population 8 'hoppers Per sq. yd.	Very Heavy Population 16 'hoppers Per sq. yd.
1	42	2,987	67.2	67.2	7.5	100.0	35	1-35	1-35	2-70
2	12	813	63.8	65.5	8.1	97.4	25	1-25	1-25	2-50
4	16	1,098	64.0	66.3	7.1	96.5	32	1-32	1-32	2-64
3	12	874	58.9	67.3	7.0	87.5**	19	1-19	2-38	3-57
11	17	1,117	55.3	66.4	7.7	83.2**	26	1-26	2-52	3-78
10	36	2,320	52.9	66.8	7.3	79.2**	16	1-16	2-32	3-48
8	13	994	51.8	67.6	7.7	76.6**	29	1-29	2-58	3-87
12	12	817	50.0	66.1	7.1	75.6**	23	1-23	2-46	3-69
6	13	1,003	49.5	67.1	7.7	73.7**	17	1-17	2-34	3-51
7	11	809	42.7	66.0	8.0	64.6**	20	2-40	3-60	4-80
9	13	1,095	39.0	66.4	6.7	58.7**	25	2-50	3-75	4-100
5	10	811	17.9	65.2	7.8	27.4**	19	--	--	--

** Highly Significant

Table 12.

Per Cent Mortality Obtained Over a Five-Day Period with Oil and Water Baits

Bait No.	Dead	Alive	Per Cent Mortality	Dead	Alive	Per Cent Mortality
	First Day			Second Day		
Check	6	50	10.0	12	53	12.2
1a	63	10	87.6	70	18	79.5
1b	50	9	84.7			
4a	78	15	83.8	67	13	83.7
4b	48	8	85,7			
	Third Day			Fourth Day		
Check	13	74	14.4	6	46	13.0
1a	18	22	45.0	8	33	19.9
1b	20	27	40.8			
4a	38	18	67.9	24	18	57.1
4b	46	22	69.1			
	Fifth Day			Mean Averages for Five-Day Period		
Check	4	49	9.5	Check		11.8
1	5	26	16.1	1		53.3
4	20	25	44.4	4		70.2

Bait No. 5 gave the poorest results of all the baits tried. It was composed of the bran that is made by grinding de-linted cottonseed hulls after they leave the cottonseed oil mills. Certain large mills were interested in having the bran tested, stating it could be put on the market at a very reasonable price. Since the mean per cent mortality for No. 5 was 17.9 and that of the check was 7.8, it seems cottonseed bran is of little value as a bait material.

Baits No. 6 (cottonseed hulls - sawdust), No. 7 (cottonseed hulls), and No. 8 (cottonseed hulls - alfalfa - leaf meal) all consist wholly or in part of cottonseed hulls. Since there is a large supply of this material available in Oklahoma, much interest was shown in having it tested as a bait. As shown in Table 11 and Figure 5, Nos. 6 and 8 gave better results than No. 7 their per cent mortality being 51.8, 49.5, and 42.7 respectively. Among the 12 baits given in Table 11 and Figure 5, they rank 7th, 9th, and 10th respectively. Among the 9 baits rated on attractiveness, as given in Table 4, No. 8 was 4th, No. 6 was 7th and No. 7 was 9th. Since, as shown in Table 11 and Figure 5, all of the cottonseed baits are rated below the sawdust baits Nos. 3, 11, and 10, the advisability of using cottonseed hulls in baits would depend upon their price as explained on p. 34. The price of hulls in Oklahoma vary a great deal from year to year, sometimes being extremely cheap, due to oversupply. Under such conditions it might be practical to use cottonseed hulls in grasshopper baits.

Bait No. 9 (sawdust 50 lbs. 0 alfalfa leaf meal 50 lbs.)

was the least effective of all baits excepting No. 5 (cottonseed bran). This low rating, it is believed, is due to the fact that the mixture of sawdust and alfalfa leaf meal spread very poorly. This belief is supported by the fact that No. 9 rated fifth among the twelve baits in attractiveness (Table 4). Probably a much smaller proportion of alfalfa leaf meal to the sawdust would give a more efficient bait. Since this change would decrease the cost of the bait it might be practical to use.

Bait No. 10 (millrun bran 25 lbs. - sawdust 75 lbs.) has been recommended by the Bureau of Entomology and Plant Quarantine and used with considerable success in the northern and western states in 1937. This bait showed to greater advantage in the dryer western section of Oklahoma than in Payne County in the north central area. No. 10 rated 6th among 12 baits in effectiveness and 8th among 10 baits in attractiveness. Its low cost of 16 cents per acre combined with its mean per cent mortality of 52.9 makes No. 10 the bait giving the most protection for the money spent (Table 11 and Figure 5).

Due to reports from the county agents and farmers it was decided to test the effect of adding molasses and amyl acetate to the materials used in No. 10. This combination was called No. 11. Since the addition of molasses and amyl acetate to bran had no significant effect it was not surprising to note that when they were added to the sawdust - millrun bait no significant change was found (Table 11).

In the case of bait No. 12 the formula was the same as that of No. 10 excepting, that white arsenic and lubricating oil were substituted for the sodium arsenite and water respectively. No significant difference was found between No. 10 and No. 12, though the water bait was slightly higher.

IV SUMMARY AND CONCLUSIONS

Much experimental work has been done on grasshopper baits since they were first tried sixty years ago. Many changes have been made in the composition, rate of applying, method of applying and time of applying baits.

Grasshopper baits were tested in Oklahoma during the summers of 1936 and 1937 by means of pan tests, plot tests, and cage tests. Twenty baits were compared as to attractiveness by 36 pan tests. Early in the morning baits were placed in pan strung in a line through alfalfa fields. Counts were made at 30 minute periods through the day of the number of grasshoppers feeding on each bait. Weather conditions were recorded at each period.

Thirteen baits were compared as to effectiveness by 148 plot tests in the summer of 1936. Plots of one acre were surveyed and the number of grasshoppers per square yard estimated. Baits were spread on these plots at 6:00 a.m., and sixty hours later the number of dead and live grasshoppers per square yard determined. The per cent mortality was determined by comparing the number per square yard before poisoning with the number after poisoning.

During June, July, and August of 1937, 12 baits were compared by 207 cage tests. One acre plots were spread at 6:00 a.m. Three hours later the plots were swept and the grasshoppers placed in small screened cages containing green food. Sixty hours later counts of the dead and live grasshoppers were made by which the per cent mortality was determined.

From the results of pan tests, plot tests, and cage tests the following conclusions were drawn regarding bait composition:

1. The addition of amyl acetate or ground lemons to baits does not appreciably increase their attractiveness or effectiveness.
2. Bran is definitely more attractive and effective than pure pine sawdust.
3. The addition of 50 per cent bran to pure sawdust distinctly increases its attractiveness and effectiveness.
4. The addition of 20 to 25 per cent of flour, shorts, and millrun bran to sawdust and cottonseed hulls increases their effectiveness.
5. Alfalfa meal shows some promise as a material to add to sawdust and cottonseed baits.
6. Fresh bait is distinctly more attractive than one-day old bait.
7. The addition of blackstrap molasses does not appreciably increase the efficiency of baits.
8. Lubricating oil (vis 30) is a practical substitute for water in baits. Preliminary tests indicate that oil is considerably more effective than water baits four or five days after spreading.
9. Cottonseed hulls are practical as bait carriers where the supply is large and the price low.
10. Rice hulls, cane pulp, and cottonseed bran are of

of little value in baits.

From the results of the pan tests the following conclusions concerning the feeding of grasshoppers on baits are made:

1. The optimum range of temperature is from 70 to 80 degrees.
2. Little feeding occurs above 90 degrees.
3. Ordinary wind velocities do not affect feeding.
4. Relative humidity does not affect feeding.
5. Cloudy skies do not directly affect feeding.
6. The time of day at which maximum feeding occurs varies greatly, but is generally reached in the forenoon.

On the basis of this experimental work and the writer's practical experience, the following conclusions are drawn regarding the control of grasshoppers with baits:

1. Bait should be spread when the air temperature is not less than 68 degrees nor higher than 82 degrees.
2. Grasshoppers should be poisoned early in the season.

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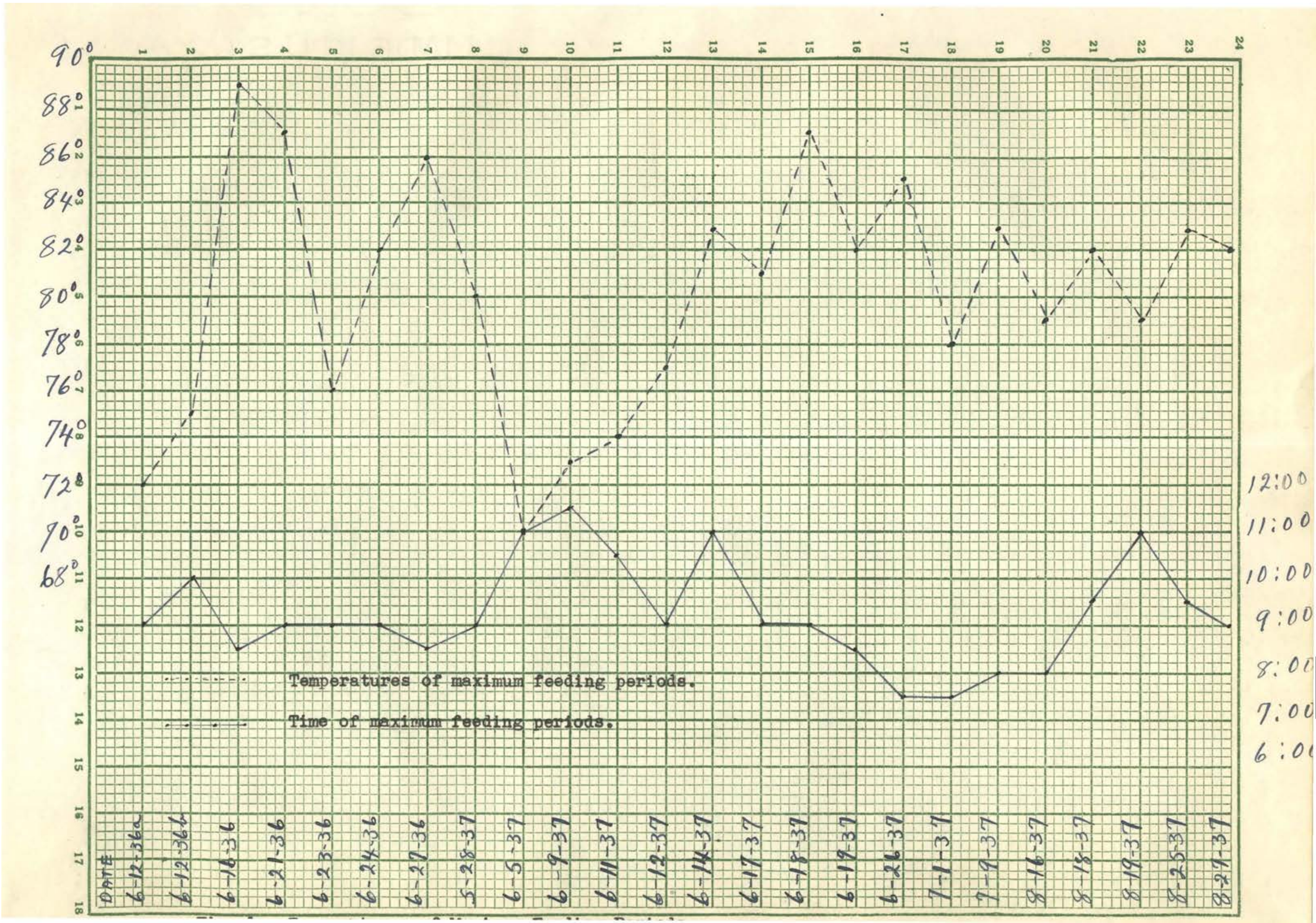

Temperatures of maximum feeding periods.
Time of maximum feeding periods.
90°
88°
86°
84°
82°
80°
78°
76°
74°
72°
70°
68°
12:00
11:00
10:00
9:00
8:00
7:00
6:00
DATE
6-12-36a
6-12-36b
6-16-36
6-21-36
6-23-36
6-24-36
6-27-36
5-28-37
6-5-37
6-9-37
6-11-37
6-12-37
6-14-37
6-17-37
6-18-37
6-19-37
6-26-37
7-1-37
7-9-37
8-16-37
8-18-37
8-19-37
8-25-37
8-27-37

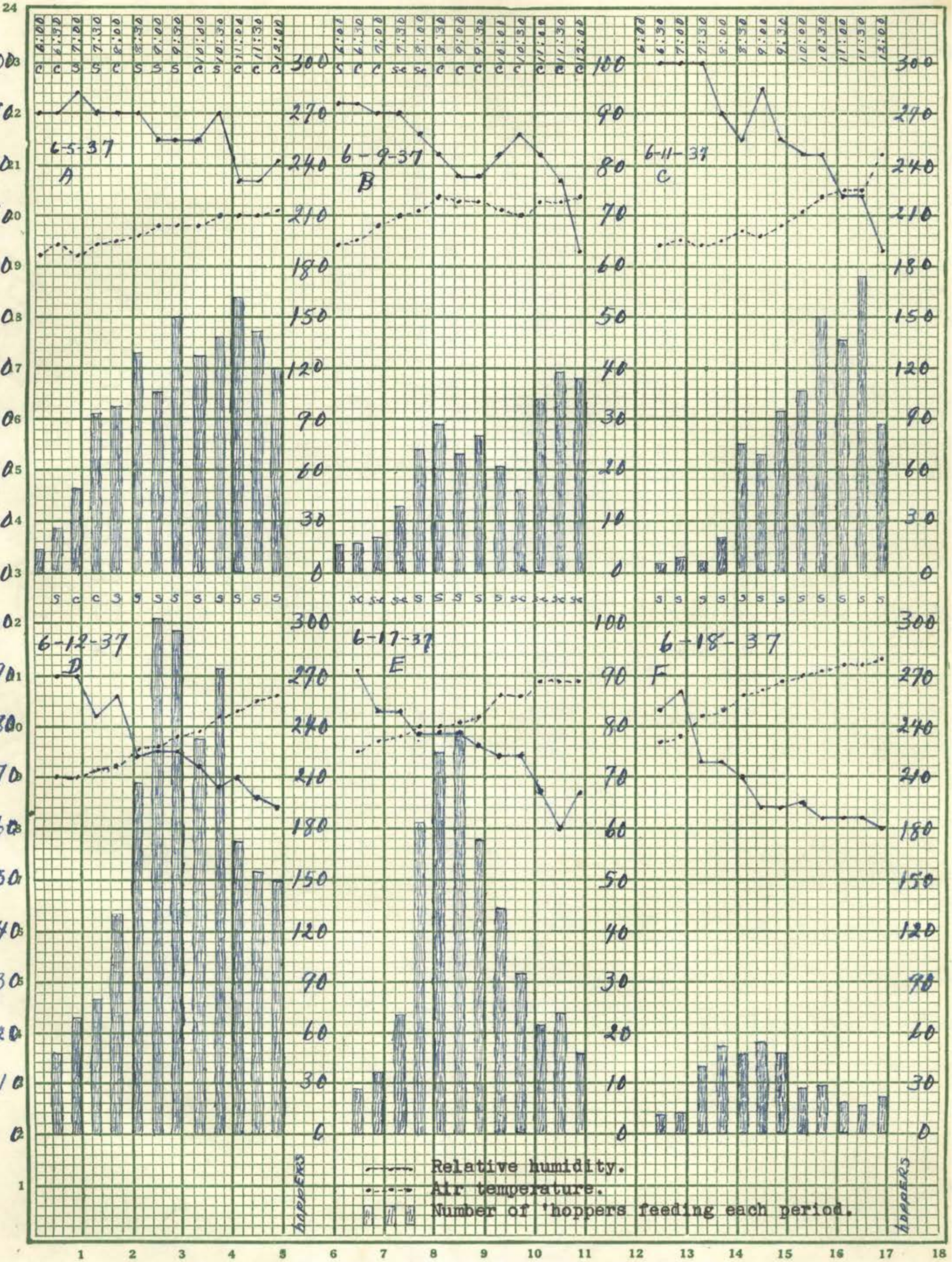

Fig. 3. Relation of Temperature and Relative Humidity to Feeding.

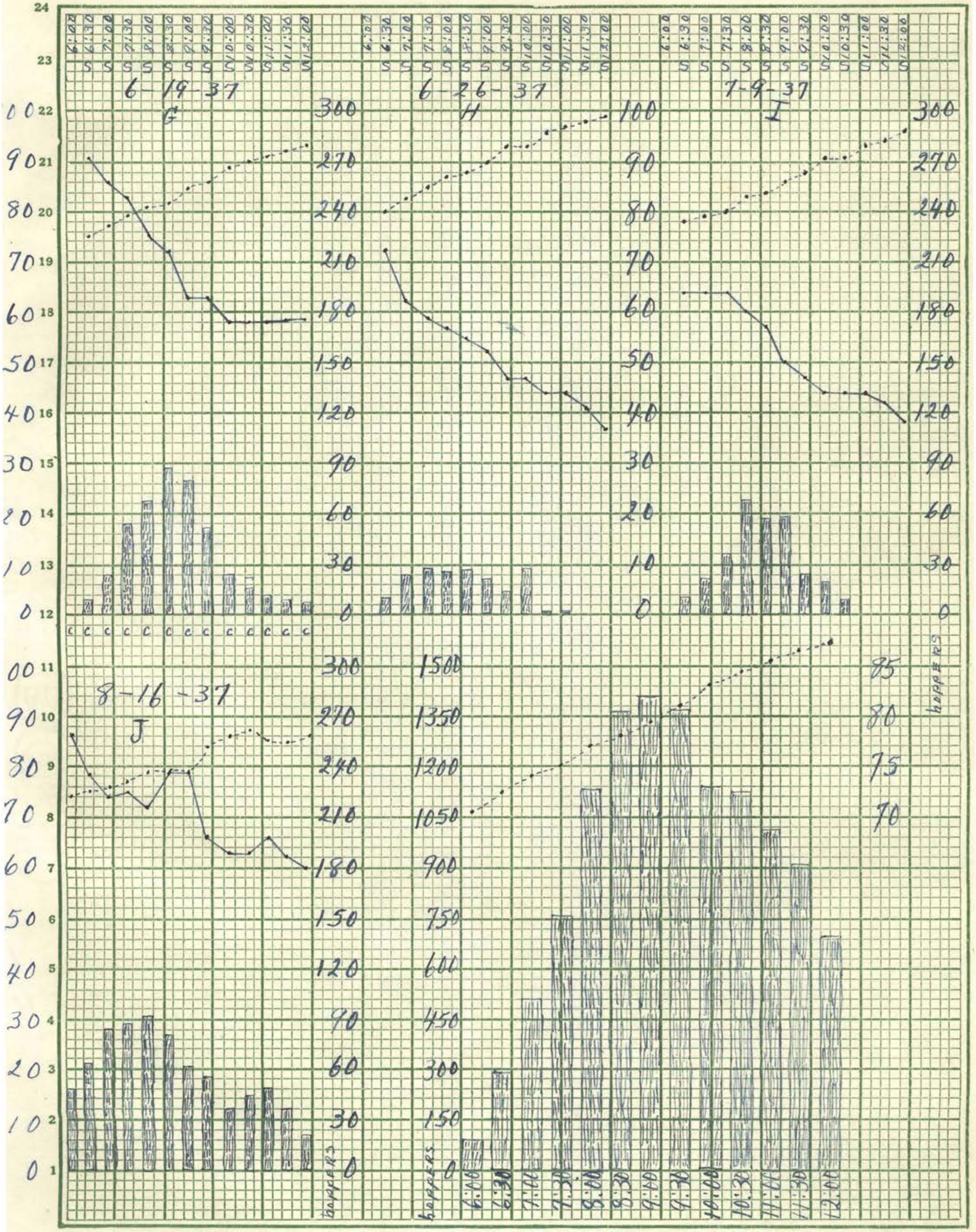

Fig. 3. (continued)

Fig. 2. Total Feeding by Periods on Seventeen Tests.

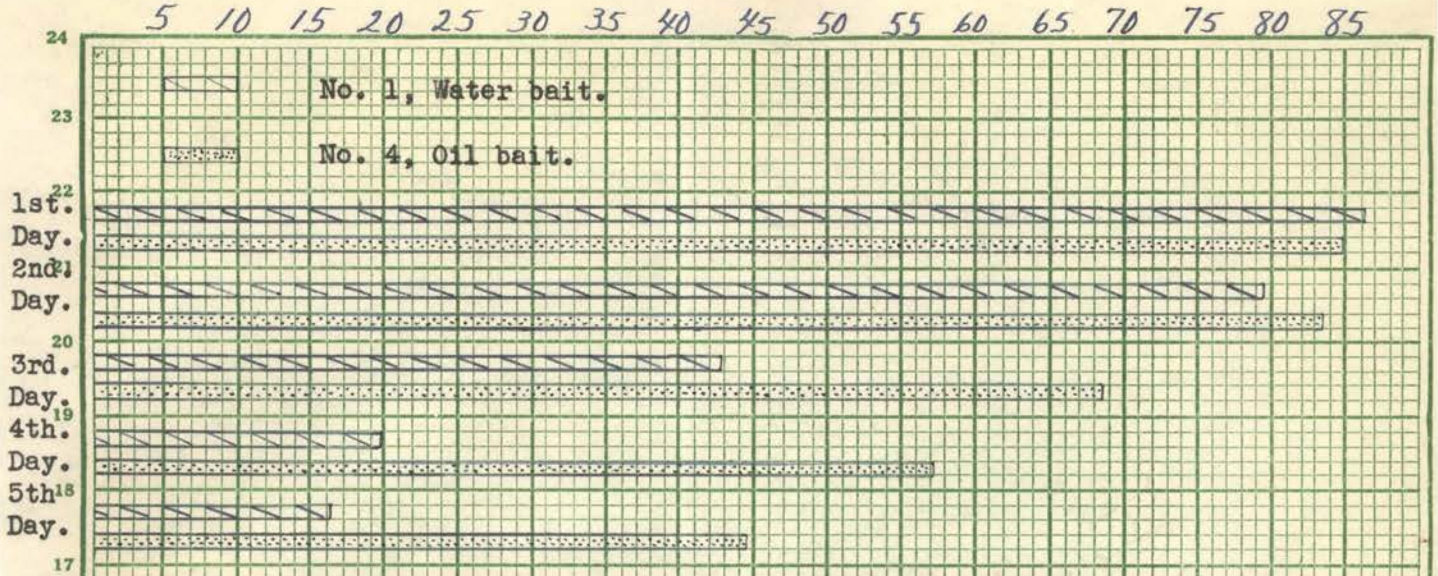

Fig. 4. Per Cent Mortality Obtained Over a Five-Day Period with Oil and Water Baits.

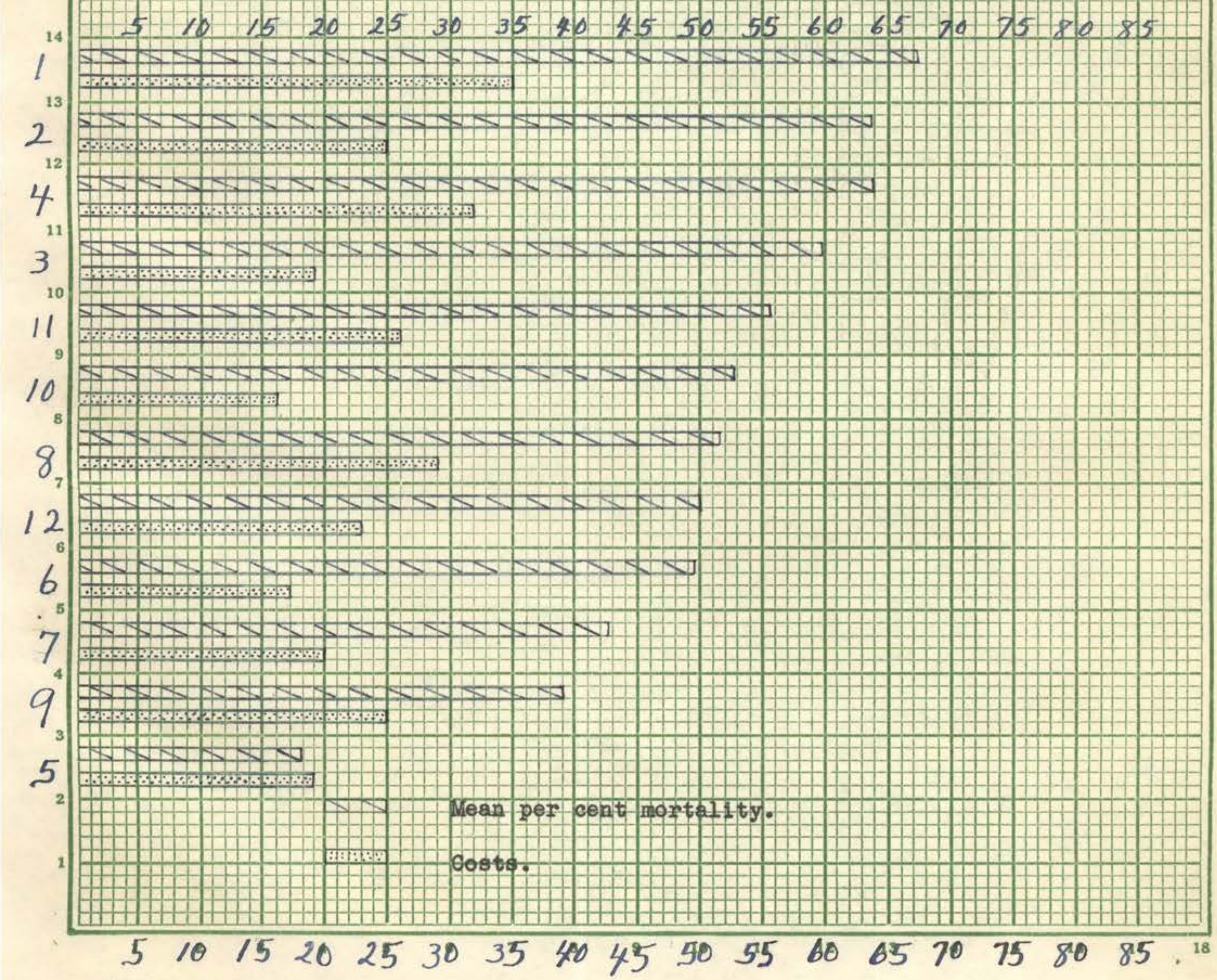

Fig. 5. Comparative Effectiveness and Costs of Baits, 1937.

Joy Adams