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Insects

U. S. DEPARTMENT OF AGRICULTURE,

BUREAU OF ENTOMOLOGY—BULLETIN No. 76.

L. O. HOWARD, Entomologist and Chief of Bureau.

FUMIGATION FOR THE CITRUS WHITE FLY,

AS ADAPTED TO FLORIDA CONDITIONS.

BY

A. W. MORRILL, Ph. D.

Special Field Agent.

Issued October 31, 1908.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
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White Fly Investigations.

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LETTER OF TRANSMITTAL.

U. S. DEPARTMENT OF AGRICULTURE,
BUREAU OF ENTOMOLOGY,
Washington, D. C., June 11, 1908.

SIR: I transmit herewith, for publication as Bulletin No. 76 of this Bureau, a report on fumigation for the white fly, as adapted to Florida conditions, by Dr. A. W. Morrill, special field agent.

The investigation of the white fly problem in Florida is now in its second year, and the results gained of immediate practical importance are those which indicate best methods of control. Fumigation with hydrocyanic-acid gas during the short dormant period in winter, when there are no winged insects, seems to afford the greatest measure of control or possible extermination. Gas fumigation under the horticultural conditions obtaining in Florida orange groves and the peculiarities of climate presents rather a distinct problem. This bulletin gives the results of the fumigation experiments of two winters in Florida, and demonstrates the entire applicability of this method of control to the white fly. This investigation has been under the general direction of Mr. C. L. Marlatt, Assistant Chief of this Bureau, with Doctor Morrill in field charge. The latter was aided during the winter of 1906–7 by Mr. Stephen Strong, formerly horticultural commissioner of Los Angeles, Cal., and an experienced fumigator, and Mr. A. C. Morgan, and during the winter of 1907–8 by Messrs. E. A. Back, W. W. Yothers, and R. S. Woglum.

The white fly is the big insect problem of Florida and other citrus districts on the Gulf coast, and the information given in this bulletin will be of immediate practical value to all citrus growers of the region indicated.

Respectfully,
L. O. HOWARD,
Entomologist and Chief of Bureau.

Hon. JAMES WILSON,
Secretary of Agriculture.

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INTRODUCTION.

The discovery of the value of hydrocyanic-acid gas as an insecticide against citrus pests is properly considered one of the most important advances in economic entomology. This gas was first used by Mr. D. W. Coquillett, who in 1886 was detailed by Dr. C. V. Riley, the Entomologist of the U. S. Department of Agriculture, to experiment with insecticides against the cottony cushion scale (*Icerya purchasi* Mask.) in California. The process was afterwards brought to its present degree of usefulness through the extensive experiments of Mr. Coquillett, and is now generally recognized in the citrus-growing sections of California as the most practicable and efficient method of controlling the black, red, and purple scales. It is now used in combating citrus scales in South Africa, New South Wales, and elsewhere, with results so satisfactory that wherever it has once been tested it has proved its superiority over all other methods.

In the eastern part of the United States Prof. H. A. Morgan conducted experiments with hydrocyanic-acid gas against citrus scales in southern Louisiana during the winter of 1892–93. Messrs. W. T. Swingle and H. J. Webber, of the Department of Agriculture, were the first to use this treatment against the white fly in Florida, conducting their experiments in February, 1894. In the winter of 1900–1901, Prof. H. A. Gossard, then entomologist at the Agricultural Experiment Station of Florida, aided during a portion of his experiments by Prof. C. W. Woodworth, of the Agricultural Experiment Station of the University of California, undertook some experimental fumigation work against the white fly. The results were sufficiently satisfactory to lead Professor Gossard to the conclusion that the efficiency of this treatment against the white fly is such that if a fumigated grove were segregated from all others, one fumigation would render it so nearly clean that it would need no additional treatment for two or three years. It was predicted that a process that has been found so valuable in other parts of the world is certain eventually to come into favor in Florida.

During the last few years certain nurserymen in Florida have made use of fumigation against the white fly with good success, treating, for the most part, small-sized trees. Other parties have tested fumigation on trees of all sizes, but, for lack of adequate equipment or of a knowledge of the most economical methods of procedure and dosage requirements, have not continued.

In January and February, 1907, the writer, aided by Mr. Stephen Strong, formerly horticultural commissioner of Los Angeles County, Cal., specially appointed in this Bureau as fumigation expert, and Mr. A. C. Morgan, special field agent, temporarily transferred from the cotton boll weevil investigations, conducted careful experiments in Orange County, Fla., in order that fumigation for the white fly might be placed upon a practical basis. Modern California methods as adapted to all sizes of trees were employed and the principal results are embodied in the present bulletin.

In December, 1907, and January, February, and March, 1908, fumigation experiments were continued by the Bureau of Entomology on a larger scale, testing the conclusions drawn from the work of the previous winter and extending the investigation to cover the ground more thoroughly. In this work the writer was assisted throughout the season by Messrs. W. W. Yothers and E. A. Back, and during the month of January Mr. R. S. Woglum was also engaged in the work. Altogether nearly 4,000 trees have been fumigated in Florida in this experimental work, under the immediate supervision of the agents of the Bureau of Entomology. It is too early to include in this bulletin more than the general results of the past winter's experimental work, but the text has been made to conform to these results as far as worked out.

There remain many details concerning the fumigation process which have demanded investigation, and at the present writing these are receiving attention by agents of this Bureau who are conducting an exhaustive study of the matter in California. The present bulletin aims to give the results of experiments in fumigation for the white fly and such information and recommendations as are of immediate value to those who may contemplate the adoption of fumigation as a practice, or who may desire first to secure a small equipment in order to become familiar with the methods of procedure. The directions given herein are believed to be sufficiently detailed to enable any orange grower to conduct fumigation, after a few preliminary tests, without the assistance of experienced hands. The recently discovered occurrence of the white fly in California increases the importance of definite information concerning the requirements as to dosage.

A new system for the estimation of dosage is recommended herein, as it is believed that the usual method of judging concerning the dosage requirements for scale-insects can not give the uniformity of results which should be obtained in using this remedy against the white fly.

CONDITIONS FAVORING OR NECESSARY TO GOOD RESULTS.

ISOLATION OF GROVE.

Isolation in an infested grove is the most favorable condition for the successful control of the white fly by fumigation. A distance of one-half mile between a given grove and the nearest infested grove is sufficient to insure against appreciable interference with the results of the treatment through the migration of adults between the groves. In many if not in most cases 300 or 400 yards is sufficient isolation to prevent the treatment being made unprofitable through such migrations. It is a common experience in newly infested groves that the section which first becomes infested may be very noticeably blackened by sooty mold for two or three years before the white fly multiplies to an injurious extent in near-by sections of the same grove or in immediately adjoining groves. The experience mentioned above indicates that in isolated groves the extermination, or nearly complete extermination, which can be obtained by carefully conducted fumigation, will result in a condition of practical immunity over a period of two or more years.

CONCERTED ACTION.

Ranking next to isolation as a factor favoring success in fumigation for the white fly, is concerted action among the owners of groves in naturally isolated groups, or among all the citrus growers in the various counties. In California the organization and support of county horticultural commissions has solved the problems connected with the attainment of the concerted action necessary for the control of various citrus pests in that State. It is predicted that the white fly can never become a serious pest where such systematic campaigns against citrus insects have been organized. In Florida, Orange County has already made a beginning toward the adoption of such measures against the white fly, having organized a horticultural commission with powers equivalent to those of similar commissions in California.[a] The officials having the matter in charge, however, have not felt justified in attempting active field work on a large scale until careful experiments shall have determined what course can be followed with a certainty of uniform results.

ABSENCE OR ELIMINATION OF FOOD PLANTS OTHER THAN CITRUS.

The presence of food plants of the white fly other than citrus trees, in citrus fruit growing sections, constitutes a serious menace and in itself often prevents successful results from remedial work. For-

[a] For the California law see Bul. 61, Bur. Ent., U. S. Dept. Agric. (1906), pp. 13–21.

tunately the list of food plants[a] is limited, and the greater number of those thus far recorded is subject to infestation only when located near or in the midst of heavily infested citrus groves. The food plants which are of most importance in connection with the white fly control are the chinaberry trees, privets, and cape jessamine, and these—except for the last, in certain sections where grown for commercial purposes—can be eradicated readily, or their infestation may be prevented where community interests precede those of the individual in controlling public sentiment. These food plants favor the rapid dissemination of the white fly from centers of infestation and their successful establishment in uninfested localities. They seriously interfere with the success of fumigation, as well as of all other remedial measures, by furnishing a favored breeding place where the white fly can regain its usual abundance in a much shorter time than would be the case if it were entirely dependent upon citrus fruit trees for its food supply. The plants mentioned, together with *Citrus trifoliata* (except where used in nurseries), and all abandoned and useless citrus trees should be condemned as public nuisances and destroyed in all communities where citrus fruit growing is an important industry. Where the destruction of chinaberry trees is impracticable for any reason, they may be rendered innocuous by taking steps to prevent their becoming heavily infested each year. This may be accomplished by either defoliating each winter or by destroying entirely all privets and cape jessamines and by thoroughly fumigating each winter all citrus trees within a distance of 200 or 300 yards of each chinaberry tree.

SEASON OF THE YEAR.

Fumigation for the white fly should be done during December, January, and February, beginning not earlier than sixteen to twenty days after the adults have disappeared, in order that all of the eggs

[a] The complete list of food plants so far as known is as follows: Citrus (all varieties), chinaberry (*Melia azedarach* and *Melia azedarach umbraculiformis*), cape jessamine (*Gardenia jasminoides*), wild persimmon (*Diospyros virginiana*), Japan persimmon (*D. kaki*), privets (*Ligustrum* spp.), *Viburnum nudum*, *Ficus altissima*, prickly ash (*Xanthoxylum clava-herculis*), cultivated pear (*Pyrus* sp.), cherry laurel (*Prunus laurocerasus*), *Prunus caroliniana*, lilac (*Syringa* sp.). Water oak (*Quercus nigra*) has been reported as a food plant of the citrus white fly, but there is no definite record of the insect reaching maturity on this plant, and the observations made in connection with the present white fly investigations show that for practical purposes oaks may be ignored as food plants of this species. Professor Gossard reports having observed larvæ of the citrus white fly on scrub palmetto (*Sabal megacarpa*). The author once observed larvæ on the banana shrub (*Magnolia fuscatum*) but apparently none reached maturity on this plant. Dr. E. A. Back has observed two live larvæ of the citrus white fly on oleander (*Nerium oleander*). These plants (oaks, scrub palmetto, banana shrub, and oleander) may be ignored absolutely as food plants unless it is proved beyond doubt that it is possible for the citrus white fly to reach maturity on them. The cultivated fig (Ficus), and the sweet bay (*Magnolia virginiana*) have been reported as food plants, but with little doubt these reports are erroneous.

deposited by these adults may have time to hatch. It is impracticable to attempt to destroy the egg stage by fumigation, or as a rule by any other direct means. The scale-like stages, however, technically known as the larval and pupal stages, are readily destroyed when the dosage is properly estimated. In Florida the month of January is, everything considered, the most favorable month for fumigating for the white fly. Ordinarily it would probably be undesirable to continue fumigation after the adults begin to emerge in considerable numbers in the spring. This time of emergence, of course, varies according to the locality and to weather conditions, but in general is between the middle of February and the first of March. It remains for further experiments to show how far fumigation may be practiced with profit at other seasons of the year. It is certain, however, that in cases of emergency, such as the checking of the spread of the fly in newly infested groves, fumigation can frequently be used to great advantage even in midsummer.

METEOROLOGICAL ELEMENTS.

Light.—Fumigation is conducted in the absence of bright sunlight, to avoid injury to the foliage which may occur when this precaution is not observed. With tents treated with oil to make them nearly gas-tight, damage is almost certain to result from daylight fumigation. With untreated tents, however, the writer has on several occasions conducted fumigation experiments with the sun fifteen minutes high without appreciable injury to the foliage. One orange tree was fumigated forty minutes, beginning at 3 p. m., with the sun shining, without any shedding or burning of foliage resulting from the treatment. The tent was placed over the tree twenty-five minutes before generating the gas, and at the beginning of the forty-minute period the temperature was 79.5° F., or 4.5° higher than the outside temperature. Twenty and one-half ounces of potassium cyanid were used, and 97.7 per cent of the white fly pupæ were destroyed. This amount of cyanid was 4½ ounces less than the amount called for by the table given in the Appendix. At the time of fumigation, the foliage on the tree was very much curled by drought and after a few rains became normal in appearance without the shedding of a single leaf. The leaves, at the time of the treatment, when torn seemed to be as dry as paper, although many pupæ of the white fly on neighboring trees in a similar condition produced adults, as did the nine specimens which were known to survive on the fumigated tree. It is probable that future experience will show that trees whose foliage is curled as a result of drought are not nearly so liable to injury by daylight fumigation as are trees whose foliage is in perfect condition.

Fumigation can safely begin with sundown, or, during the fumigating season in Florida, between 4 and 5 o'clock p. m. On dark, cloudy days fumigation seems entirely safe at any time with untreated tents.

Wind.—The effect of wind upon the results is so marked that fumigation should not be attempted with anything stronger than a slight breeze, particularly if the tents have not been rendered gas-tight or nearly so by the use of a "filler." It has been found, with an untreated tent, that with a dosage sufficient to destroy 100 per cent of white fly pupæ, a brisk breeze renders the results so uncertain that the effectiveness may be as low as 30 per cent in some sections of the tree, while in others the destruction of the insect may be complete.

Atmospheric humidity and dews.—The presence of moisture in the form of dew does not seem to have any deleterious effect upon the foliage, although in California it is generally considered necessary to materially increase the dosage in such cases to insure the effectiveness of the work against scale insects. Prof. H. A. Gossard[a] concluded that "moisture did not seem to interfere with the efficiency of the work, unless the leaves were almost dripping, when it became a factor of much disturbance, though not as great as we had thought probable."

The experiments conducted by the writer and assistants during January and February, 1907, show that moisture on the foliage during the period of exposure has no marked effect on the foliage or upon the efficiency of the gas against the white fly. In the six instances where the leaves were wet with dew, examination showed that 100 per cent of the insects were destroyed in all cases but one, and in this only a single specimen out of 102 under observation, before and after fumigation, survived the treatment.

The results of the tests concerning the effect of atmospheric moisture on the efficiency of the fumigation treatment are given in Table I.

TABLE I.—*Effect of atmospheric moisture on efficiency of fumigation.*

Experiment No. [b]	Air humidity.	Condition of tent.	Condition of leaves.	Per cent of insects killed.	Amount of cyanid used.	Amount of cyanid recommended in tables; 45 minutes exposure.
	Per cent.				*Ounces.*	*Ounces.*
30.7	100	Wet	Wet	100	30	24
40.2	94+		Moist	100	32	27
45.12	100	Wet	Wet	100	15¾	14
45.21	87	Damp		89.3	9	11
45.22	87	Damp		99.8	13¾	18
45.25	96	Damp	Moist	100	33½	32
45.27	100	Wet	Wet	99.7	36½	34
50.2	97		Moist	100	28	19
60.2	64	Damp	Dry	100	22	26½
60.19	90	Damp	Dry	100	27½	26½

[a] Bul. 67, Fla. Agr. Exp. Sta., pp. 647–648.

[b] The number preceding the decimal point indicates the length of exposure.

On several occasions it was observed that the tent felt somewhat damp when being handled, although the humidity recorded by a standard sling psychrometer had not reached complete saturation. On other occasions, as shown by the above data, the foliage was covered with a dew like a fine mist when the sling psychrometer indicated as much as 6 per cent below complete saturation. For practical purposes, however, the moisture on the leaves may be considered as indicating a condition of 100 per cent atmospheric moisture. Blank spaces in the table indicate that no note was made concerning this particular point, although the tent was evidently "wet" in experiments 40.2 and 50.2 and the leaves were evidently "dry" in experiments 45.21 and 45.22. In the experiments summarized in Table I the possibility of reducing the efficiency of the gas through absorption by the moisture on the leaves and tent had to be taken into consideration. To eliminate this feature and to determine the effect of the gas on larvæ and pupæ of the white fly when leaves are wet artificially, tests were made by wetting the leaves both by dipping and by means of an atomizer. The results are summarized in Table II.

TABLE II.—*Effect of artificially wetting leaves on efficiency of fumigation.*

Experiment No.	Air humidity.	Amount of cyanid used.	Amount of cyanid recommended in table.	Total number of insects under observation.	Per cent of insects killed.	Number of insects on leaves wet artificially.	Per cent of insects killed on leaves wet artificially.	Method of wetting.
	Per cent.	*Ounces.*	*Ounces.*					
30.6	44	20	29	242	71	21	95.2	Dipped.
40.6	47	17½	21	392	88	149	90.6	Sprayed.
40.7	55	8½	13	132	80	40	87.5	Dipped.
40.8	61	17¼	29½	223	96	93	98.9	Sprayed.
40.9	54	12	27	342	93	20	95	Sprayed.
40.13	63	24	28	736	100	567	100	Dipped.

In the above experiments—omitting the last one, in which all insects were killed—1,331 insects were under observation. Of these, 323 were on leaves wetted artificially. The weighted average of the insects killed on these leaves is 92.5 per cent. Of the 1,008 insects on the dry leaves 852, or 84 per cent, were killed. This seems to be of considerable significance in view of the fact that in every instance where less than 100 per cent of the insects were killed, the percentage of killed was greater on the artificially wetted leaves than on the dry leaves.

Taken as a whole the results summarized in the two foregoing tables show conclusively that moisture on the leaves in the form of dew does not reduce the efficacy of the gas in destroying the insects, but possibly increases it. In the experiments in which moisture was a factor no injury to the foliage followed, even when the dosage was increased fully one-half above the amount called for by the table in the appendix of this bulletin. The results give no justification to the practice of some fumigators who, as has been stated, increase the dosage when the tents and foliage are wet with dew. It seems that the difficulty in handling wet tents is the only consideration for which it is necessary to cease work on foggy nights, everything else being favorable.

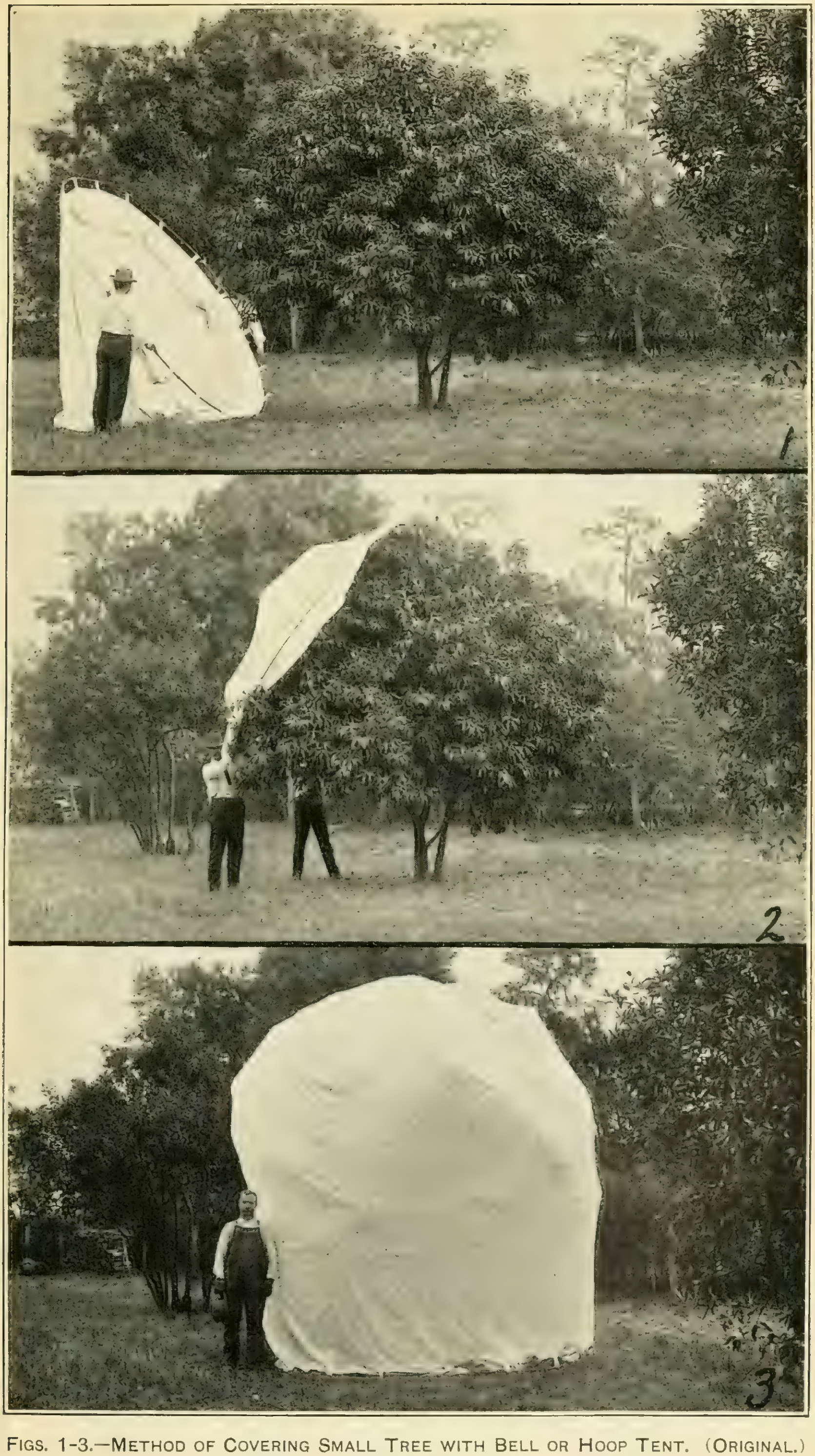
SIZE OF TREES AND REGULARITY OF SETTING.

While it is true that it is possible to place a fumigating tent over any citrus tree regardless of size, the author strongly recommends that orange growers make a practice of pruning large seedling trees so that they will not exceed 28 or 30 feet in extreme height. Such pruning will greatly reduce the cost of labor in fumigating and will be of considerable advantage from the standpoint of picking the fruit. It is probable that the now generally recognized all-around advantage of low-pruned fruit trees applies equally well to citrus as to other kinds of fruits. Another consideration of importance is the regularity in the setting of orange groves and the proper spacing of trees. In Florida various factors have resulted in many groves being too crowded or too irregularly set to permit of the easy handling of fumigating tents. While it is well to bear these things in mind to the end that all Florida groves may gradually be adapted to reduce the labor and expense of fumigation, yet even under present conditions it is exceedingly rare that fumigation is rendered absolutely impracticable by the size of trees or the irregularity of their setting.

EQUIPMENT.

TENTS.

Styles of fumigating tents.—Two styles of tents are now in use for orchard fumigation, the bell or hoop tent (Pl. I.) and the sheet tent. The first is bell-shaped and held open at the mouth by a hoop of ¾-inch gas pipe. Tents of this style are preferable for use only when the trees in a grove are uniformly less than 12 feet in extreme height. Sheet tents are made in the form of flat octagons and, being adaptable for trees of all sizes, are in California used almost exclusively. Plate I, figure 3, shows a tree which is 14 feet in extreme height and 14 feet in extreme expanse, covered by a hoop or bell tent. When the tent is in position covering the tree the measurements are: Height, 13 feet, and diameter, 12 feet. Hoop tents are not always easily placed in position over trees of this size, and it is believed that ordinarily a sheet tent is more desirable for trees of all sizes. A third style of tent which will be found useful in fumigating small trees is the box tent in the form of a rectangular prism. This will probably prove advantageous for trees 5 feet or less in height. The light wooden framework supporting the cloth cover gives a form to the



FIGS. 1-3.—METHOD OF COVERING SMALL TREE WITH BELL OR HOOP TENT. (ORIGINAL.)

inclosed space which permits of economical use of chemicals with greater uniformity of results.

Construction of tents.—The construction of the box covers such as suggested in the foregoing paragraph is a simple matter and convenient patterns will suggest themselves at once to anyone desirous of fumigating small trees. The framework should be light but well braced, and for a covering either 6½-ounce drill, painted to render it as nearly gas-tight as possible, or oilcloth is recommended.

Prof. C. W. Woodworth, of the California experiment station, gives the following directions for cutting the cloth for bell tents:[a]

> All of these tents are made in the same manner, and are the most economical in cloth of any tents made. Commonly the tent is made by the "cut and fit" method. These tents may be made with scarcely any loss, if cut according to the following directions: Measure off strips of a length equal to twice the height plus one-tenth the diameter of the tent desired. These will make two strips each by marking the exact middle and measuring off on one edge from the middle line one-quarter of the diameter of the tent and on the other one-half the diameter. Now, take a long strip of molding and bend it so as to touch these three points and mark off the curve so produced. This allows for the seam. In making up, sew the two cut edges together in each pair of strips.

As has been stated, sheet tents, or more properly covers, are flat, regular octagons. The dimensions are sometimes stated in terms of the true diameter (i. e., the distance between opposite corners), but for practical purposes the distance between parallel sides should represent the size of the tent, for the reason that this represents within about 2 feet (which must be allowed to rest on the ground) the distance over the tallest tree that a given sheet can cover measuring from the ground on one side to the ground on the other, over the center of the tree.

Hereafter in this bulletin the size of octagon covers as stated should be understood to refer to the distance between parallel sides. The specifications should be carefully worked out before beginning the construction of a sheet tent as well as of other styles. First, the dimensions of the tallest tree which the tent is required to cover should be estimated. This may be accomplished by throwing a tape attached to a reel over the top of the tree and measuring from ground to ground. When covered, the weight of the tent will reduce the extreme height of the tree in most cases by from 2 to 4 feet, according to the weight of the tent and form of the tree. It will be well to allow at least 4 feet of the tent to rest on the ground when covering the largest tree. The desired size having been determined, a diagram of an octagon should be constructed on paper, as indicated in figure 1. Each side of the octagon when constructed will be equal approximately to two-fifths of the distance between the parallel

[a] Circular No. 11, Cal. Agr. Exp. Sta., pp. 9–10.

sides of the octagon. The number of square yards of cloth required is about 18 per cent, or between one-sixth and one-fifth less than for a square the sides of which are equal to the distance between parallel sides of the octagon.

In California 8-ounce army duck has been used almost exclusively for making sheet covers, while in Cape Colony, South Africa, a No. 10 duck ranking in weight between 12-ounce and 15-ounce is commonly used. The heavier weights are not only more durable but presumably confine the gas better. A good grade of $6\frac{1}{2}$-ounce drill, however, as shown later by the results obtained with a bell tent of this material, seems to be fully equal to the 8-ounce duck commonly used in California. Until careful experiments shall have determined the relative tightness of various weights of duck it is recommended that sheet tents be constructed throughout of 8-ounce duck or of 8-ounce duck in combination with a "skirt" of $6\frac{1}{2}$-ounce drill. The author has seen a sample of 8-ounce drill which is no more expensive than the best brands of duck of this weight, but is evidently far superior as regards tightness. Anyone contemplating the ordering of a fumigating outfit should procure as many samples as possible of different brands of suitable cloth and select the closest woven brand.

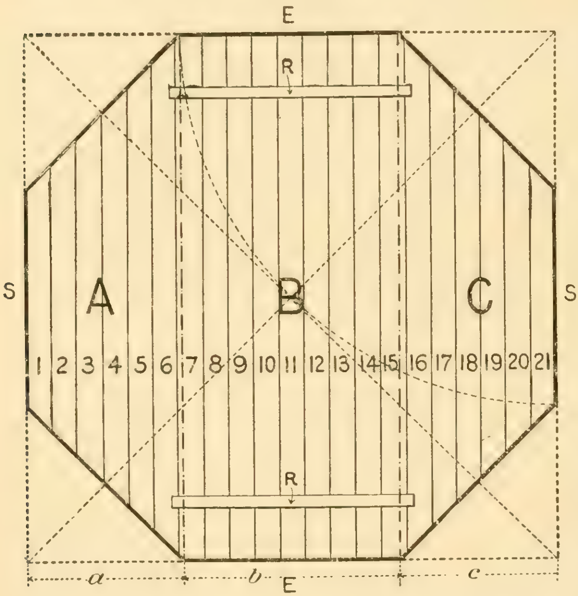


FIG. 1.—Plan for construction of octagonal sheet tent 50 feet across, showing lines used in constructing octagon: *A*, *C*, side sections; *B*, central section of full-length strips; *E*, *E*, so-called "ends" of tent; *S*, *S*, so-called "sides" of tent; *R*, *R*, reinforcements; 1–21, strips of duck $29\frac{1}{2}$ inches wide, overlapped $\frac{1}{2}$ an inch at the seams. (Original.)

The strips when cut should be overlapped three-eighths or one-half inch and double stitched and all raw edges should be hemmed. In calculating the number and length of strips the overlapping will reduce the width of the cloth from three-fourths inch to 1 inch. As an illustration of the method of calculating the length of the strips used in making an octagonal tent of 8-ounce duck, 50 feet may be taken as the desired size. This is equal to 600 inches and the width of the cloth, if 29.5 inches, will be reduced to 28.5 if overlapped one-half inch at the seams. By dividing 28.5 inches into 600 inches the nearest multiple is found to be 598.5 inches, or 49 feet and 10½ inches, which is sufficiently close to the desired width for practical purposes. The number of strips in a tent 598.5 inches wide is 21. The middle section B (fig. 1) is approximately two-fifths the entire width, or 239.5 inches. Deducting this from 598.5 inches, the entire width, the remainder, 359, equals the sum of the widths of sections A and C. These sections being equal, the width of each is 179.5 inches. The number of strips in each section can now be readily calculated. The 21 strips should be numbered on the diagram from left to right. Section A requires six strips and 8.5 inches of the seventh. Similarly, section C requires six strips, beginning at the right (twenty-first to sixteenth, inclusive), and 8.5 inches of the fifteenth. Section B requires the remaining 20 inches of strip No. 7, 20 inches of strip No. 15, and seven entire widths, thus making the total of 21 strips required.

The cutting of the cloth can be done without waste if the details of construction are well planned. In the above tent seven strips 50 feet long (49 feet 10½ inches) should first be cut for section B. Strips Nos. 7 and 15 are next cut and the outside corners cut at an angle of 45 degrees, as indicated in the diagram. Each strip for sections A and C is cut shorter by its own width outside at each end than the strip preceding it. Thus the required lengths of the side strips are found by matching the inner edge of the new one to the outer edge of the one before it. It is desirable to have the central section, B, made up entirely of full-length strips so that the stress will not be across seams. The stress is so slight, comparatively, in the side sections A and C, that this is not an important point.

Shrinkage of the goods after being thoroughly wet is an important consideration in the economical construction of fumigating tents. In order that the tents approximate a regular octagon, after having been used for fumigating purposes, it is necessary either to have the goods thoroughly shrunk before cutting or to make allowance for subsequent shrinkage by cutting the strips longer. A test made with a brand of 8-ounce duck commonly used in California for fumigating tents showed that the shrinkage lengthwise of the goods amounted to 7.5 per cent, and, crosswise 0.9 per cent; this means that in a 50-foot tent the shrinkage would result in the full-length strips shortening 3¾ feet, while the tent would shrink less than 6 inches crosswise of the strips. Such irregularities might be remedied by a skirt of 6½-ounce drill, but it is simpler to plan to have each strip cut longer by a given amount for each 1 per cent of difference in the lengthwise and crosswise shrinkage. In the case referred to above this difference is 6.6 per cent, and each per cent represents an actual difference of 6 inches. A 50-foot tent constructed in this manner would therefore measure before shrinkage 52¼ feet (49 feet 10½ inches + 3 feet 4 inches) lengthwise of the strips through the middle section, and 49 feet 10½ inches crosswise of the strips. After shrinking, the dimensions would be approximately 49 feet 4½ inches in each direction. The two sides of the octagon which are formed by the ends of the full-length strips are known as the "ends" of the tent and the sides of the octagon which are parallel with these strips as the "sides" of the tent.

By gathering the cloth around a tightly-rolled wad of burlap and tying on an iron ring, a convenient arrangement is made for attaching the hooks or poles when covering trees. (See fig. 2.) In the case of the smaller sizes of sheet tents, which are to be handled with simple poles, these rings are unnecessary, attachments being made in the manner hereafter described. For large tents, measuring more than 42 or 45 feet, it is probably best to use the rings in all cases. It is most convenient to have one of these rings located a few feet in from each of the four corners of the middle section of full-length strips (fig. 1, *B*). In general, the distance in from the margin should be from one-twelfth to one-tenth of the distance between parallel sides of the tent, and the distance between the two rings on each side should be from one-third to two-fifths of the distance between parallel sides. To the ring mentioned a chain link is sometimes attached (*e*), called a "jingler," the object being to indicate the position of the ring when the operator shakes the tent, enabling him readily to locate it at night.

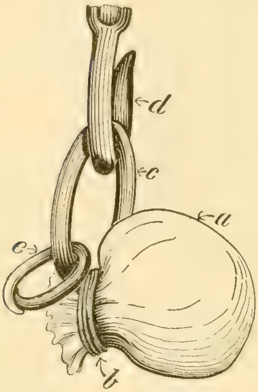


FIG. 2. Method of attaching hooks to tent when covering trees with aid of derricks: *a*, Tent gathered around ball of burlap or other suitable object; *b*, stout cord for attaching ring; *c*, catch-ring; *d*, hook on pulley block; *e*, lap link or "jingler." (Original.)

In order to provide for the increased stress on the cloth at the points where these rings are to be located, a reenforcement should be stitched on near each of the "ends" of the tent. The main stress in handling a tent is directly behind the catch rings or places of attachment when poles are used without rings. There is also considerable stress across the tent directly between the two rings or places of attachment. Both of these stresses may be provided for by a reenforcement consisting of one-half width of the goods used in constructing the tent, sewed entirely across the full-length strips of the middle section and extending 2 or 3 feet onto each of the side sections. These reenforcements are located in accordance with the directions given in the preceding paragraph and as shown in figure 1 (*R*, *R*).

A skirt of 6½-ounce drill is of considerable advantage in reducing the weight, especially in the case of the larger sizes of tents. This drill is usually about 28 inches wide, and when a skirt is to be used allowance is made for one or two widths in constructing the diagram and in figuring for the cutting of the 8-ounce duck. Sometimes the skirt is run all around the margin, but it is preferable to have the full-length strips (section B) extended the entire length of the tent and the drill sewed to the three sides of section A and of section C. When the skirt extends all the way around, when shifting the tent by means of poles or uprights, the rings should always be located on the duck inside of the skirt, to avoid too great stress upon the lighter material.

Painting, oiling, mildew-proofing, and care of tents. Various methods have been used to preserve and to increase the tightness of fumigating tents. Linseed oil was one of the first materials tested for increasing the tightness of the cloth,[a] but experience has shown this to be undesirable when used either by itself or in combinations, on account of the deterioration in the strength of the cloth and the liability to burn or rot when long left folded. Painting the cloth with black paint, with an inferior grade of glue, called "size," and with a mucilaginous juice of the prickly pear cactus (*Opuntia* sp.) are three methods mentioned by Mr. D. W. Coquillett in a report dated in October, 1890, as in use in California. In recent years these three methods have all been used more or less, the last the most extensively of the three. At present the most usual practice of California fumigators is to use untreated tents or tents proofed against mildew by dipping and boiling in a solution of tannin. This last treatment is not considered of any value in rendering the tent tighter except by ordinary shrinkage, which would be accomplished as well in due course after using one or two nights, particularly in Florida, where heavy dews are usual. The method of treatment with the tannin solution, as reported by a committee on fumigation appointed by the Claremont (California) Horticultural Club and published in various horticultural and agricultural papers, is as follows:

To prevent ruination by mildew when the tents are damp, they must be dipped. This is done in a large tank, made either of galvanized or boiler iron. These should be 3 by 10 feet and 2½ feet deep. The boiler should be rounded. This must be on a good arch, so as to permit a fire under it. The smoke pipe or chimney of the arch must be high, to secure a draft. A derrick made by three poles above the tank, supplied with pulleys and a rope, makes dipping easy and permits raising of the tent and dripping after dipping is completed. It also aids in keeping the tent from the bottom of the tank and burning, which must be avoided. The tank is filled to near the top with water and made very dark by adding a half barrel of oak extract or tannin. This is well stirred. The tannin should not be added until the water is boiling. The tent is lowered into the tank of boiling water and extract and boiled for half an hour. It is

[a] Report of Commissioner of Agriculture, 1887, Report on the Gas Treatment for Scale Insects, by D. W. Coquillett, p. 126.

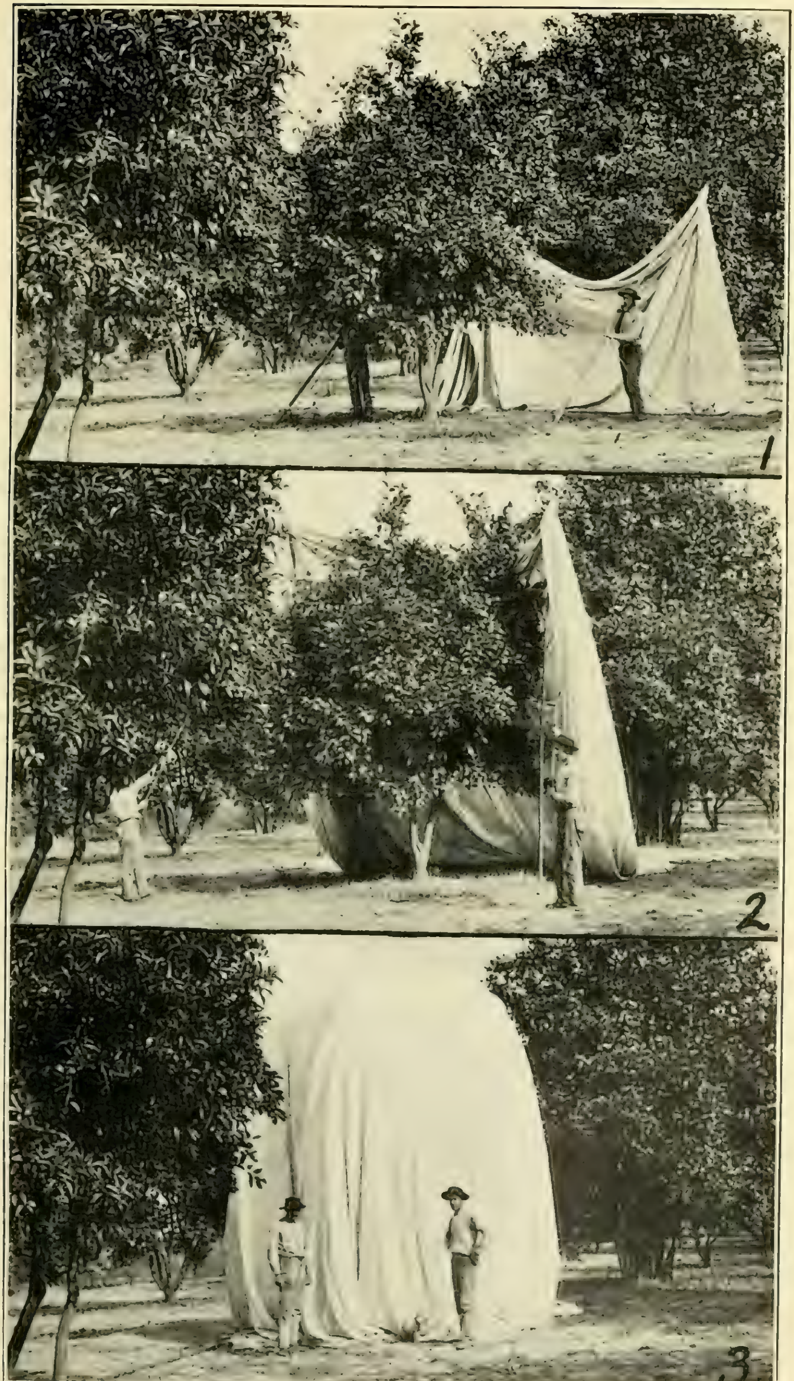
now raised from the water and after dripping ceases it is spread out to dry. The tank is filled again and the tannin is added until the color is a reddish brown, and then another tent may be dipped.

In Florida fumigating tents become thoroughly wet nearly every night they are in use, but even when untreated will not deteriorate to any great extent during two or three months' use if thoroughly dried each day, and more especially before being finally rolled up for storage during the seasons when not in use. Tents are conveniently dried each day by simply leaving them on the last tree covered until dried by the sun. The edges of the tent should be straightened out as soon after sunrise as possible, and folds in the tent should be arranged from time to time to facilitate drying. Such work, of course, should not ordinarily be considered as part of the work of the fumigating crew, but can be readily attended to by some laborer employed at the grove. It is considered by some fumigators that when tents are treated with oil it is unsafe to leave the trees covered during bright sunlight, but untreated tents can be safely dried in this manner. Drying is probably hastened by pulling the tents partly off so as to make an open space on one side to give circulation of air. Frequently it is a good practice to pull a tent wholly or partially over two trees in order to facilitate drying. When tents are dry, to prevent wetting by rain and subsequent trouble in drying, they should be rolled up as compactly as possible and arranged to shed water as well as practicable, or they may be covered with waterproofed ducking or stored for the time being in a dry place.

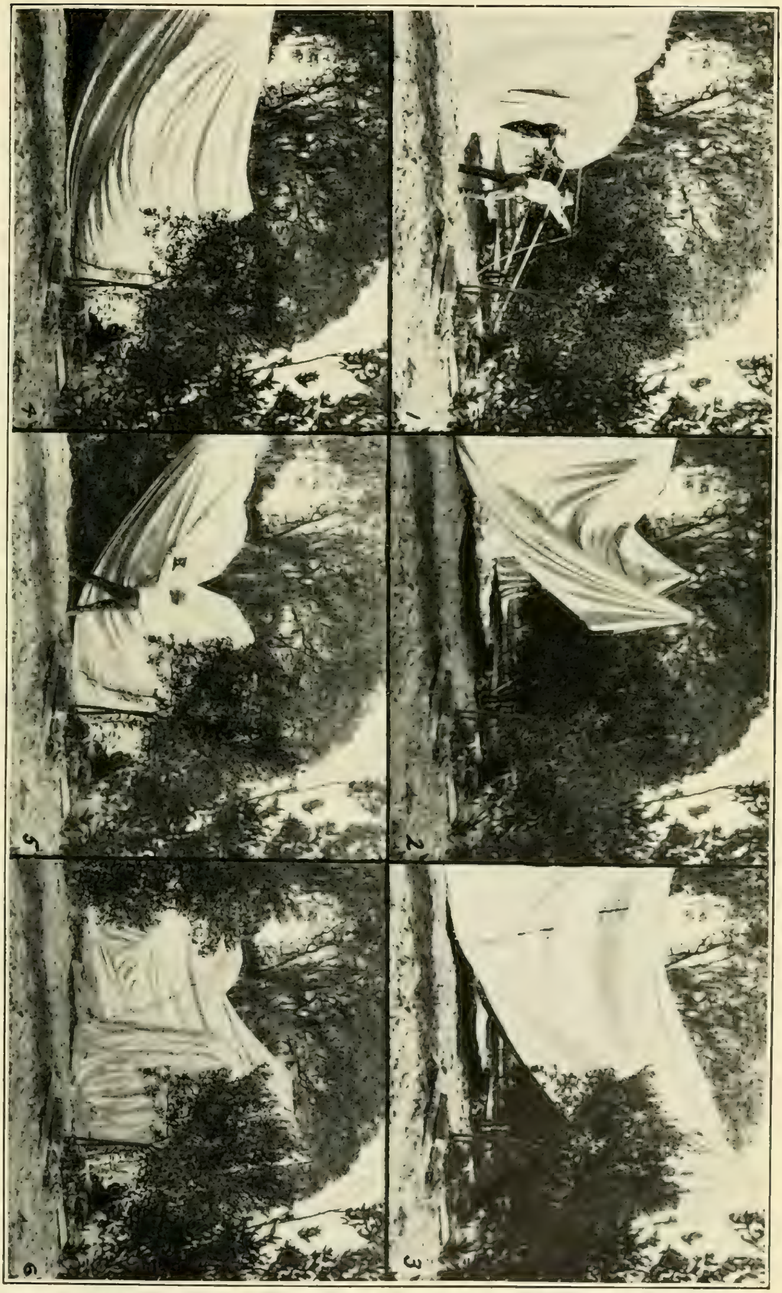
Tents must be kept in repair during the fumigating season and examined frequently during the daytime for holes which need patching. If tents are always pulled lengthwise of the strips of the cloth, there is little danger of tearing, except when there is much dead wood on the trees. One of the tents used by the agents of the Bureau of Entomology during the winter of 1906–1907 was used to cover upward of 100 trees without any injury of this kind.

POLES AND UPRIGHTS.

Poles and uprights are used, as shown in the illustrations (Pls. II, III), for raising the front edge of the fumigating tents when covering a tree or pulling the tent from one tree to the next in the row. The simple poles are as a rule used for tents not exceeding 48 feet in diameter, and usually vary from 12 to 20 feet in length, according to the height of the trees to be covered. In California straight-grained Oregon pine 2 inches in diameter is generally preferred for poles not exceeding 18 feet in length; for poles longer than 18 feet the diameter should be 2½ inches. In the Gulf regions it is recommended that seasoned cypress poles be used, as these are much lighter than the available pine. Although only a single pair need be used with an



FIGS. 1-3.—METHOD OF COVERING SMALL TREE WITH SHEET TENT BY MEANS OF POLES. (ORIGINAL.)



FIGS. 1-5.—SUCCESSIVE STAGES IN THE OPERATION OF SHIFTING A SHEET TENT FROM ONE TREE TO THE NEXT IN THE ROW. FIG. 6.—FIRST TENT READY FOR INTRODUCTION OF CHEMICALS; "TENT MEN" SHIFTING THE SECOND TENT IN THE SERIES.

[The tents are considerably larger than necessary for the trees shown in the photographs.] (Original.)

outfit of as many as twenty-five or thirty tents, extra poles should always be on hand as a provision against breakage. A one-half inch rope of either manila or cotton, about one and one-half times the length of the poles, is attached about 3 or 4 inches from the top of each one that is in use. The tops of the poles are constructed in various styles for catching the rings on the tents. The end of the pole may be cut to allow the ring to slip over the end for a short distance, for instance 1½ or 2 inches, and to hold the rope in position. Two hardwood pegs driven through auger holes about 1½ inches apart at right angles to one another will serve this purpose. The most convenient form for general use is the simple rounded top over which the cloth of the tent is doubled and held in place by a half hitch of the rope (Pl. II, figs. 1, 2). The lower end of the pole should be pointed to prevent its slipping on the ground when the tent is being lifted.

For use with sheet tents which are too large for convenient handling with the poles described, a pair of uprights or derricks is needed. These are somewhat heavier poles, with braced crosspieces at the bottom to prevent them from falling sidewise when in an upright position, and each is provided with a pulley at the top (see Pl. IV, fig. 2). When not attached to the ring in the tent the swinging block is hooked to a ring bolt or stout staple located on the upright near the tops of the braces. The poles are 25 feet or more in length, from 3 to 4 inches in diameter at the base and tapering to from 2 to 3 inches in diameter at the top. They may be made of straight-grained knotless pine or seasoned cypress. Wherever the latter can be obtained it is preferable to pine on account of its lightness. As shown in Plate IV, figure 3, crosspieces about 1 by 3 inches in section are spiked or bolted to each side across the bottom, and brace pieces about 2 by 4 in section extending from between the ends of the brace pieces to the main pole are bolted in position. The crosspieces should be 6 feet in length for derricks 25 or 26 feet high and increasing to about 7½ or 8 feet in length for 32 or 33 foot derricks. In the writer's experience derricks are sufficiently long that are within 2 to 3 feet of the extreme height of the trees to be covered, as a consequence of the elasticity of the citrus branches and the fact that within this distance of the extreme top the branches are almost invariably slender. A guy rope one-half or five-eighths inch in diameter and about one and one-half times the length of the upright is attached to the top of each, just above the pulley block. It is convenient to have these ropes easily removable so that they can be used in tying the tents into compact bales when rolled up for transportation or storage. The lifting tackle consists of a rope of the same size as the guy rope and a little less than three times as long as the upright. One end of this is attached to the fixed pulley block at the top of the upright, passes through the movable block, then through the upper fixed block, and the free end is usually tied to one of the brace pieces.

MISCELLANEOUS REQUIREMENTS.

According to the method of procedure hereinafter described and recommended for use in fumigating for the white fly, when an outfit of more than four or five tents is in use, a cart or stone drag and a horse may be desirable for carrying the materials from tree to tree. An ordinary hand push-cart can be recommended as convenient for use in some cases. When a horse or a hand push-cart is not available, a box-like tray (Pl. IV, fig. 1) with handles should be constructed. This should be large enough to contain a supply of acid and cyanid for all of the trees covered at one time by the set of tents in use. One-half of the tray should be reserved for as many 3-quart pitchers as may be needed and for the graduate, and the other half should be provided with compartments for the bags of cyanid, if weighing is done by day, or an open box for the loose cyanid if the weighing is done as each tree is fumigated. A torch should be fixed over the center of the tray, and if the cyanid is weighed as used there should be a strip of board across the tray to serve as a platform for the balances. Balances are preferable to spring scales for use in weighing the cyanid. They should not be larger than necessary for weighing 40 ounces of cyanid at once. For containing the acid temporarily, stoneware churns of a capacity of 3 or 4 gallons are much used in California, and can be recommended for use in Florida. Frequently several 3-quart pitchers are more convenient than the stoneware churns. A measuring glass of 16 ounces capacity is needed for measuring the acid, and an extra measuring glass should be provided for use in case of breakage. The acid is dipped into the measuring glasses by means of a long-handled enamel-ware dipper, or poured in from a pitcher. For carrying water a couple of large pails are needed.

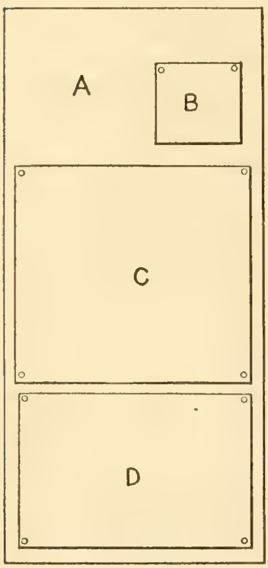


FIG. 3.—Plan for schedule board, showing convenient arrangement: *A*, space for resting lantern temporarily; *B*, scratch pad; *C*, dosage table; *D*, diagram of grove. (Original.)

The one who measures the acid and generates the gas should be provided with rubber gloves of good quality and long enough to cover the wrists well, or even the entire forearm. For generating the gas, earthernware jars from 1½ to 5 gallons capacity are necessary, according to the size of the trees and dosage required. Extra jars should be provided to obviate possible inconvenience in case of breakage. Cylindrical jars are preferable to those which narrow at the top, as the chemicals are much more likely to boil over in the latter than in the former. The cyanid, after being weighed, may be put into paper

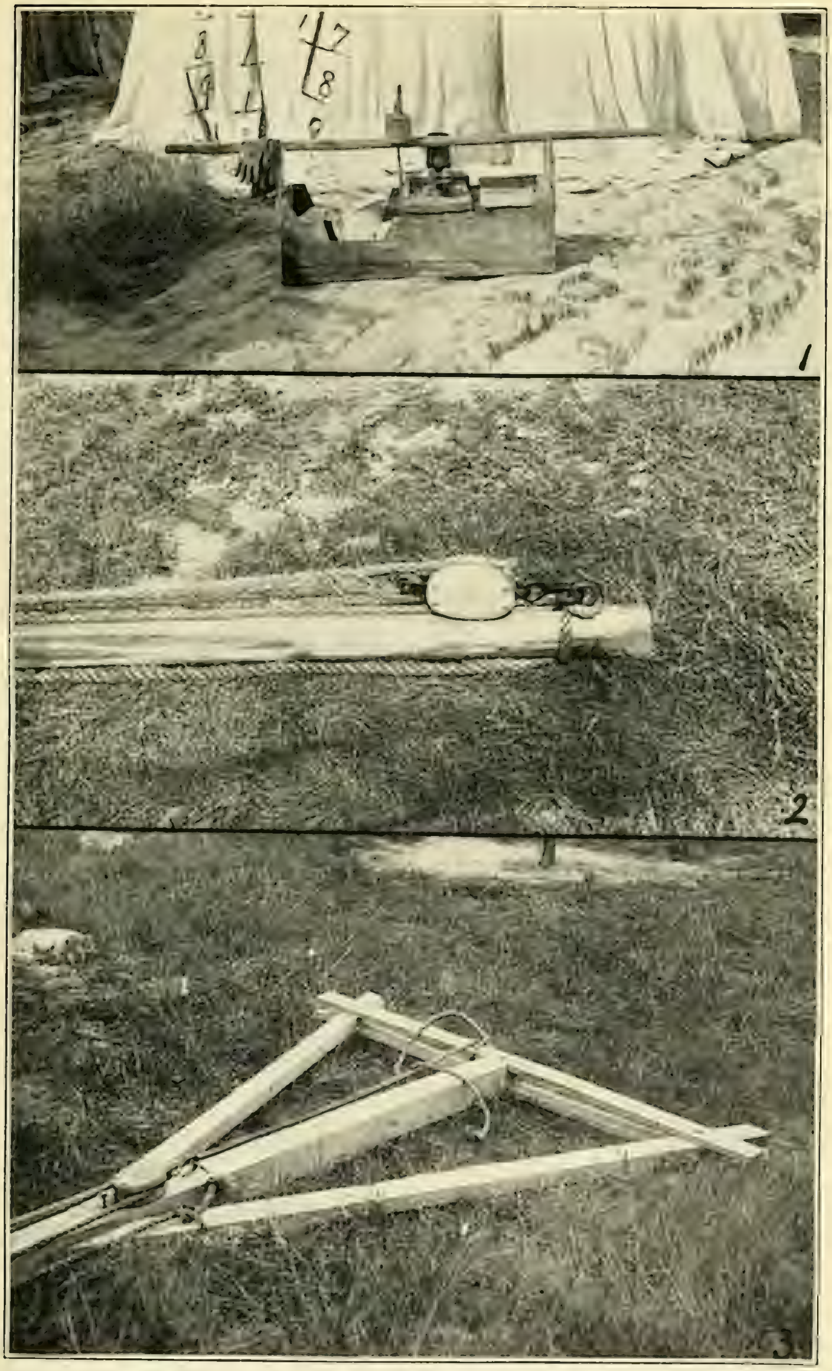


FIG. 1.—COMMISSARY TRAY: OPEN COMPARTMENT (TIN LINED) FOR CYANID AT RIGHT, BALANCES AND TORCH IN THE MIDDLE, COMPARTMENT FOR ACID PITCHERS AND GLASS GRADUATE AT LEFT. FIG. 2.—TOP OF DERRICK, SHOWING METHOD OF ATTACHING PULLEY AND GUY ROPE. FIG. 3.—BASE OF DERRICK, SHOWING METHOD OF CONSTRUCTING BRACES. (ORIGINAL.)

bags or into tin cans, or it may be emptied directly from the scoop into the generating jar. A spade or shovel should be on hand for use whenever it is necessary to weight down the edges of the tent by a few shovelfuls of earth and also for use in burying the contents of the jars. A copy of the table of dosage required for the white fly and found in the appendix of this bulletin should always be on hand. A convenient arrangement for handling the diagram of the grove and the dosage table when fumigating is illustrated by figure 3. This represents a board upon which the position for setting the lantern temporarily, and the positions for attaching diagram of the grove, dosage table, and scratch pad are indicated. For the board a side of an orange box is very satisfactory. This should be strengthened by two laths nailed across the grain on the rough side. On the

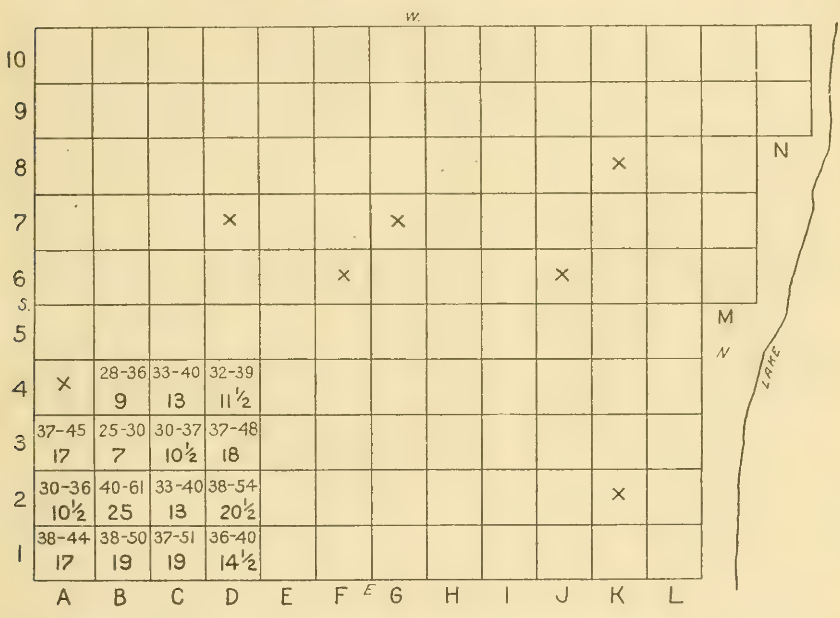


FIG. 4.—Diagram of regularly set grove in process of fumigation with an outfit of four tents: X, X, trees missing. (Original.)

smooth side at the bottom the diagram of a portion of the grove (fig. 5) should be fastened with thumb tacks. This diagram should include as much of the grove as can be fumigated in any one night and should be dated and preserved after the work for the night has been checked off on the original diagram (figs. 4, 5) of the grove as a whole. Immediately above the diagram the dosage table (fig. 3, *C*) should be located. If the board is smooth it may be painted white and the table copied thereon with pencil. If the table is on cardboard it may be fastened with thumb tacks. Above the dosage table a scratch pad (fig. 3, *B*) should be fastened in the upper right-hand corner, while the space (fig. 3, A) in the upper left-hand corner is left for the fumigator to set his lantern while he is writing down on the diagram the dimensions of the tented tree and the amount of dosage. It will be found convenient to attach a pencil to this board with a short string.

The diagrams of the grove are prepared as shown in figures 4 and 5, representing a small grove set in regular and alternate rows respectively. When set with any form of regularity the individual trees may be conveniently referred to by numbering the rows in one direction and lettering them in the other. Thus the first tree of row No. 1 is called 1A, the second 1B, etc., while in the other direction the trees are referred to as 2A, 3A, etc. In measuring the circumference of the trees or in checking the correctness of the estimates based on pacing, a 75 or 100 foot tape attached to a reel is needed. Water-tight barrels are required for containing the stock of water for use during the night.

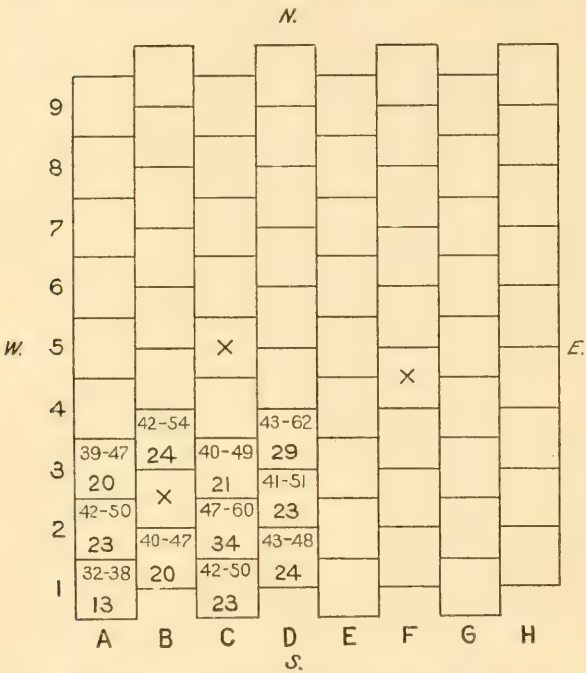


FIG. 5. Diagram of grove with alternating trees; first four rows in process of fumigation with four tents; three sets of trees fumigated, the tents being moved from south to north: X, X, X, trees missing. (Original.)

When weighing the cyanid a tin scoop is sometimes useful, and leather gloves should be provided for the one who does the weighing. When weighing of the cyanid is to be done during the day five wooden boxes, with hinged covers, of a size that will conveniently fit into the cart, or one box with six compartments, should be constructed for use in holding paper bags of cyanid in doses of 1, 2, 5, 10, and 20 ounces, respectively. Experience will show the number and style of lanterns and torches required. A hammer, hatchet, and other incidentals can be procured as found necessary.

CHEMICALS.

DEGREE OF PURITY REQUIRED.

The materials used in generating hydrocyanic-acid gas are potassium cyanid (KCN), sulphuric acid (H_2SO_4), and water. The cyanid and acid should be purchased of a reliable dealer. The cyanid should be guaranteed to be 98 or 99 per cent, which is practically chemically pure. The acid should be guaranteed to be 66° [a] and, as additional assurance, it would be well to have a sample tested by a druggist or by the fumigator himself by using an acid hydrometer. This instrument is inexpensive and can be obtained through any druggist. A firm or hard cyanid should be obtained rather than a soft or porous product.

HANDLING, AND NECESSITY FOR PROTECTION FROM MOISTURE.

Potassium cyanid can be purchased in boxes of 200 pounds each. The cyanid readily absorbs moisture, and for this reason after a box is opened it should be kept constantly covered with burlap sacks and protected against rain when necessary. When only a few trees are to be treated and the box of cyanid is not to be completely used, within a few days at the most, it is recommended that it be stored in large-sized tin cans with covers made practically air-tight by means of cheese cloth or muslin. The acid when used in large quantities is purchased in drums containing about 1,500 pounds. In smaller quantities it is sold in carboys containing a little less than 200 pounds. The carboys make convenient receptacles for handling in the groves. In emptying from a drum into carboys a large funnel of glass or sheet lead is useful. When the carboys are boxed and not otherwise provided with handles, strips of wood may be nailed along parallel sides projecting at each end, so as to make convenient handles for two men. If carboys can not be obtained or the quantity of acid used does not require temporary containers for such amounts, large jugs may be used. In all cases the containers, except when in use, should be stoppered. For this purpose wooden plugs, made tight with asbestos, such as can be bought in sheets from hardware dealers, may be used. When the acid is to be stored in carboys for more than a few days the plugs should be made extra tight by means of plaster of Paris. For water required in the generation of the gas anything that is reasonably clean will answer the requirements.

PROPORTION OF WATER AND ACID.

The proportion of the materials theoretically required for a complete chemical reaction is 1 part of potassium cyanid, 1 part of acid, and 2 parts of water. In practice, however, an excess of acid up to one-fourth

[a] Sixty-six degrees sulphuric acid is 93 per cent strength.

more than the actual requirement is ordinarily used, while it is generally considered that the use of three or four times as much water as acid reduces the danger of shedding of the leaves from excessive dosage. The experiments conducted by the writer relating to this point have thus far given only negative results by failing to show any relation between the proportion of the water and acid and the effect of the gas upon the insects or the foliage. In 66 of the experiments summarized hereafter a record was made of the proportion of the water and acid. In nearly every case the object was to determine the minimum dosage required, and while the record included the proportions of the water and acid no effect of the variation in this regard was looked for until the results were summarized. The chances, therefore, were equal in regard to the selection of a dose of the required amount for greatest utility in the various tests. The results in connection with the proportion of water and acid used are given in the Table III:

TABLE III.—*Results obtained with varying proportions of water and acid.*

Parts of water to one part of acid.	Number experiments in which 100 per cent of white flies were killed.	Number experiments in which less than 100 per cent of white flies were killed.	Total.
2	1	2	3
2½	9	5	14
3	10	17	27
3½	0	1	1
4	11	9	20
5	0	1	1
Total	31	35	66
Less than 3	10	7	17
3 or more	21	28	49

It will be observed from the table that the results seem to favor the smaller amounts of water in proportion to the acid rather than the larger amounts. The data are not extensive enough to establish this conclusively, and it is not improbable that the difference in the percentage of white flies killed has no connection with the proportion of water and acid. It is at least evident, however, that there is no marked difference in favor of the use of water in a proportion greater than necessary for the complete chemical reaction. The Association of Horticultural Inspectors in 1903 adopted the formula usually expressed 1–2–4, meaning 1 part of cyanid, 2 of acid, and 4 of water. Mr. Wilmon Newell's laboratory experiments[a] lead him to conclude that this formula permits the volatilization of an apparently maximum amount of prussic (hydrocyanic) acid.

[a] Bul. 15, Georgia State Board of Entomology, pp. 21–24, 1905.

The element of heat due to the mixing of the acid and water is recognized as an important factor in generating the gas. According to C. P. Lounsbury[a] very nearly the maximum amount of heat is evolved when equal volumes of acid and water are used, and he advises against the use of more than 2 volumes of water to 1 of acid.

The point in question is one of those now under investigation in California by agents of this Bureau. Until conclusions are reached the writer would recommend that the chemicals be used in the proportion of 1 part of cyanid, 1 part of acid, and 3 parts of water, or 1–1–3. This formula is recommended for the present on account of results of experiments reported herein and upon which the table given in the appendix is based, being obtained with an average of 3 parts of water to 1 of acid. Future experiments may justify the California practice from the standpoint of danger to the foliage from the use of the smaller amounts of water. In the experience of the writer as reported herein, the injury to the foliage has been too slight to show any relation to the proportion of the chemicals.

PROCEDURE.

METHODS OF HANDLING TENTS.

Sheet tents.—Octagonal sheet tents, or covers, are placed in position over trees by means of the changing poles and derricks which have been described. A tree which measures in extreme height between 30 and 35 feet can be covered and made entirely ready for the generation of the gas in less than two minutes if the work is not interfered with by the too close planting of trees. Smaller trees usually require from one to two minutes, according to size. When the changing poles are used (Plate II, figs. 1, 2; Plate III, figs. 1–5) in covering small trees, one man on each side of the tree places the ring over the end of his pole if catch rings are used, or if not, makes a double fold of the cloth over the end of the pole and makes a half-hitch over it with the rope to prevent it from slipping off. With the pointed end of the pole on each side about opposite the center of the tree they then raise the end of the pole and attached tent about 8 feet, or until the pointed ends hold without slipping, and, holding on to the rope, step forward and away from the tree and pull the tent into position. Some operators prefer, after attaching the tent to the end of the pole, to stand with one foot on the pointed end and raise the pole entirely by means of the rope. Knots tied in the ropes at convenient intervals near the end are of great assistance in pulling. If the trees are so large that they require tents too large and heavy for handling by two men and yet not large enough to require the use of derricks, a third man may be employed to advantage. The edge of the tent is made fast to the

[a] Agricultural Journal (Cape Town), 1902, p. 4.

end of each pole as before, but the two operators station themselves with the rope in hand at the foot of their respective poles while the helper raises the end of each pole in turn, so that the operators can use their ropes to advantage. The committee of the Clermont Horticultural Club, of California, in their report heretofore referred to, recommended that four men, or two for each pole, be regularly employed. When trees are close planted or there is fear of breaking branches by changing the tent from one tree to the next, or there is dead wood threatening to tear the tent if simply dragged off, the practice of "skinning it off" will be found to be useful. In this method the attachments of the poles are made at the far side of the tent and the cloth slides over itself as the tent is pulled from one tree to the next.

In handling sheet tents by means of derricks (Pl. V, figs. 1, 2; Pl. VI, fig. 1) four to six men can work to best advantage. The writer has, however, with one assistant successfully handled a sheet with 26-foot derricks. After placing one of the derricks in the position for raising the tent the guy rope was fastened to a tree while the second derrick was raised. Each operator then held the guy rope by means of a loop through which the elbow was placed, giving the use of both hands while raising the tent with the tackle. Ordinarily two men should not attempt to cover a tree by themselves, particularly if there is a slight breeze. When four men are available for handling sheet tents with derricks, they proceed as follows: The sheet is pulled into position back of the tree to be covered, with the rings located one on each side. The derricks are placed one on each side of the tree, flat on the ground and their bases parallel, either directly opposite the center of the tree or within a distance of 3 or 4 feet back, whichever experience with trees of various sizes and widths of rows may show to be best. Two men station themselves, one at the base of each derrick with guy rope in hand. The other two men go to the opposite ends of their uprights and raise them to a vertical position with the assistance of the men at the bases, who pull with the guy ropes, standing on the cross pieces as long as necessary to prevent slipping. The second two men now steady the derricks while the first two walk forward and take a position for holding them in place by means of the guy ropes. The derricks are now brought to a position where the tops are 3 or 4 feet beyond the vertical in order to prevent the weight of the guy rope from causing them to fall forward prematurely. The two men at the bases of the derricks now attach the hooks of the swinging blocks to the rings of the tent and by means of the tackle raise the front edge of the tent to the tops of the derricks. These men may now tie their hoisting ropes to the braces or hold them tightly by hand while the other men pull on the guy ropes, causing the derricks to fall forward, pulling the tent over the tree. Five or six men may be needed to cover very large seedling trees such as are

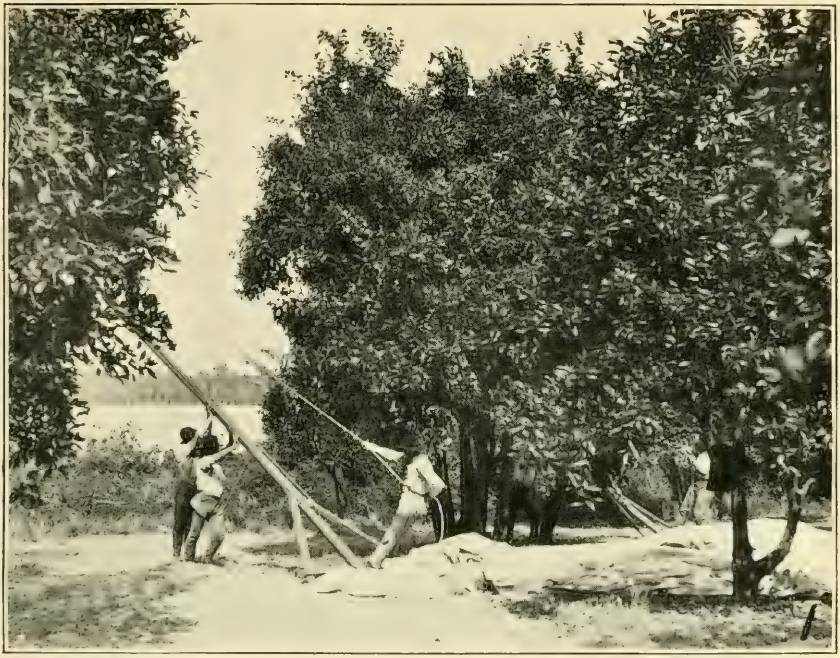


FIG. 1.—RAISING 33-FOOT DERRICKS TO AN UPRIGHT POSITION. (ORIGINAL.)

FIG. 2.—DERRICKS IN POSITION (ONE ON EACH SIDE OF TREE) SUPPORTED BY GUY ROPES; PULLEYS HOOKED TO CATCH-RINGS IN THE TENT. (ORIGINAL.)

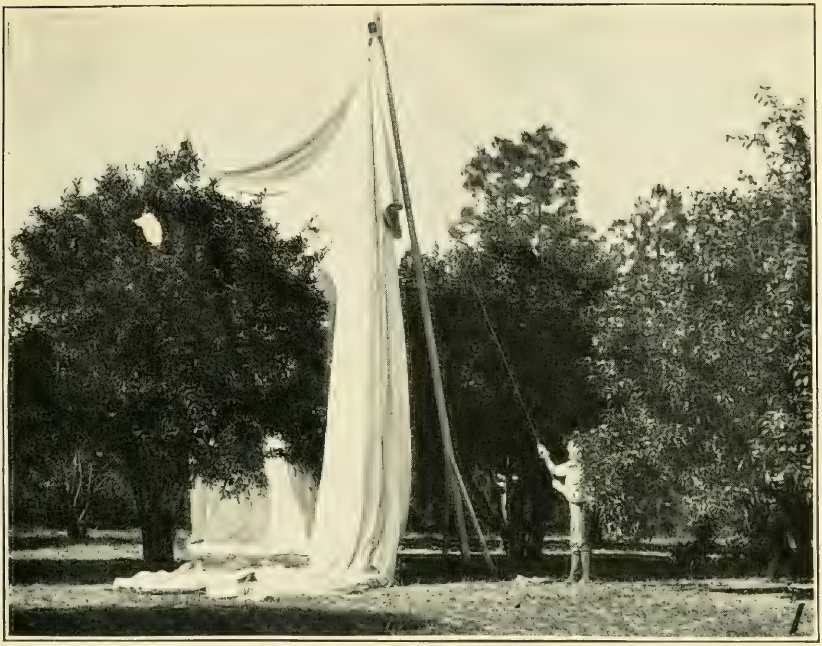


FIG. 1.—FRONT EDGE OF SHEET TENT RAISED TO TOPS OF DERRICKS, READY TO BE PULLED OVER TREE. (ORIGINAL.)

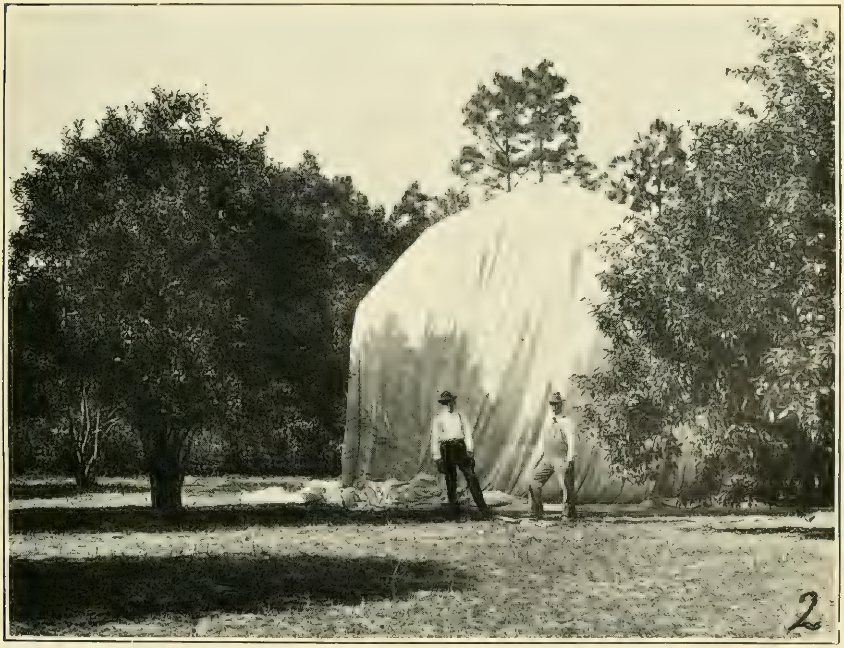


FIG. 2.—SHEET TENT READY FOR INTRODUCTION OF CHEMICALS. (ORIGINAL.)

common in Florida, especially when the trees are closely set. After adjusting or "kicking in" the edges, the tent is ready for the introduction of the chemicals.

Whether simple poles or derricks are used, tents are usually changed from one tree to the next in the row by making the attachment as described and pulling the tent directly off from one onto the other. When there are only a few large trees to fumigate and the tents at hand are singly not sufficiently large to cover, two can be frequently used to advantage, placing them in position from opposite sides and having them overlap as much as possible without interfering with tightness at the ground.

It is best to have the tents large enough so that not less than 2 feet of the edge will rest on the ground at any point when adjusted and ready for fumigation. Sometimes it may be necessary to weight down the tents at certain points by means of a few shovelfuls of earth. Carelessness of the workmen charged with adjusting the tents at the ground would result in seriously curtailing the benefits from fumigating a grove. When arriving at the end of a row, or on other occasions when it is desired to uncover a tree without at the same time pulling the tent in position over another, the tent is usually dragged off by hand. If there is dead wood present, however, to avoid the possibility of injuring the tent, removal with the poles or derricks may be advisable. It is well to call attention again to the desirability of always pulling the tent lengthwise with the strips, whether in changing the tent from tree to tree or in dragging off from a tree after treatment.

Bell tents. The method of covering trees with bell or hoop tents is so plainly shown by Plate I as to require but few words of explanation. The cloth should fall over the hoop on the side farthest from the tree, in order to bring the center of the tent about over the center of the tree in covering. Usually two men, one on each side, can easily throw the tent entirely over the tree, but if the tree to be covered requires nearly the full capacity of the tent it will be necessary to pass around to the front of the tree and pull the tent down into position with the hoop resting on the ground. Ordinarily the cloth which extends below the hoop makes the tent sufficiently tight at the bottom when the hoop is resting flat on the ground. An extra man with a pole or rope may be necessary to assist in handling the largest sizes of hoop tents, when they are used to cover the largest trees possible. In changing from one tree to the next in the row a little experience will show what is the quickest and easiest method. Tents of this pattern are at present little used in California, the sheet tent being greatly preferred even for small trees.

MEASURING TREES.

Necessity for measurements. —The rule followed by some California fumigators in estimating the dosage for scale insects is to give an amount which in the manager's judgment is as large as each tree will stand without injury to well-matured growth. Tender growth is almost invariably injured by a proper dosage, but this loss is not considered of consequence. In Florida, however, there is usually little or no new growth until toward the close of the season to which fumigation for the white fly should be limited. It is obviously impossible, even for an experienced fumigator, without measuring, to judge of the size of trees so accurately as to avoid overdoses, on the one hand, wasting a small percentage of the chemicals, and, on the other hand, underestimates with the consequent lack of effectiveness. The difference between an effective dosage as a treatment for the white fly and one which would produce injury to the tree is not large in many cases,[a] and careful estimation of dosage seems essential for economy and success in fumigation for this insect. Even among fumigators considered most successful in California, there is a wide diversity of opinion as to the quantity of chemicals required for trees of the same size, as shown by the observations of Mr. S. J. Hunter, reported by Professor Woodworth, and by the published recommendations as to dosage by various writers. The significance of this in California is that there is a great difference between efficiency against the scale insects treated and danger to the trees; and the practice of basing dosage on guesses as to the dimensions, either before or after covering, necessarily results in the danger of underestimation of the dosage requirement on the one hand and a needless waste of chemicals on the other. A study of the table given in the appendix, showing the dosage recommended for successful work against the white fly with untreated tents,[b] proves the physical impossibility of a fumigator approximating such dosage without a definite knowledge of the size of the space inclosed and of the ratio of the number of cubic feet of contents to the square feet of surface through which the gas gradually escapes. This can be obtained only by actual measurements. The only two dimensions which it is at all practicable to obtain are the circumference of the tented tree at the base and the distance over the top from ground to ground. The system here recommended will, by insuring satisfactory results, prove the most economical for adoption

[a] The experimental work conducted in Florida during the winter of 1907-8 has shown that the liability of injuring citrus trees from overdosing is frequently dependent upon the physiological condition of the trees as affected by the nature of the soil, the soil moisture, and the chemical fertilizers used in the grove.

[b] Water-shrunk or its equivalent as regards tightness. It should be borne in mind that mildew-proofing with tannin, etc., is not supposed to increase tightness more than does the normal shrinking.

by any citrus grower contemplating the use of fumigation for the white fly. This has been thoroughly demonstrated by the experimental work conducted in the winter of 1907-8, when, as has been stated, approximately 4,000 trees were fumigated.

Methods followed in experimental work.—The measurements of tented trees in the experiments conducted in January and February, 1907, were made by means of a tape measure attached to a reel. In obtaining the distance over in each case the end of the tape was held in one hand while the reel was thrown over the center of the tent and the measurement made from ground to ground. For the purposes of the experiments, accuracy being desired as far as possible, measurements were made in two directions, from east to west and from north to south. In each case care was used to have the tape pass as nearly as possible over the center of the tree regardless of the highest point. Of 72 tented trees measured in two directions, 70 per cent were found to vary 12 inches or less in the two measurements, 15 per cent to vary from 13 inches to 24 inches, and 11 per cent from 25 inches to 50 inches. The average variation was 12 inches and the maximum 50 inches. Inasmuch as it is recommended that in using the table appended hereto the number in the first column next above the actual measurement (when the actual measurement is more than 6 inches above an even number) be selected in estimating the dosage, it is evident that in nearly all cases a measurement over the top of the tented tree in one direction, together with the circumference, will show the dosage with sufficient accuracy for practical purposes. A fumigator should, however, in using the table and knowing the measurement over in one direction, make allowances in case the irregular shape of the tree makes the single measurement over the top fall short of indicating the true size.

A new scheme for obtaining measurements.—The measuring of the tented tree by means of the tape, as described, requires two men, owing to the difficulty of getting the tape over the center of the tree. Ordinarily it requires only one or two minutes at the most to obtain these measurements, but when more than a few trees are to be treated a simpler and quicker process is necessary. One man can quickly obtain the circumference by using a tape provided at the end with means for attaching to the tent, while he walks once around the tree to the starting point, unreeling the tape as needed. For attaching the tape to the tent some form of metal clamp, such as is usually found in stock at gentlemen's furnishing stores, is suggested. In fumigating on a large scale the use of a tape causes considerable trouble, owing to unavoidable tangling and misplacing, especially when used at night. One of the operators, however, should always estimate the circumference of the tented tree by pacing. This can not be done with sufficient accuracy without considerable preliminary experience—obtained by measuring the first ten or fifteen trees covered, both with the tape and by pacing, and comparing the results. In pacing, the actual distance traveled will of course always be greater than the circumference as measured by the tape. With a little experience the proper allowance can be estimated with sufficient accuracy.

For obtaining the distance over the top of the tented tree the author has devised a plan which will so simplify the careful estimation of dosage in conjunction with tables such as the one presented in the appendix that a far greater uniformity of results and important saving of materials will follow its adoption. This method consists in marking the tent as shown in figures 6 and 7 and in Plate VII. The tent is first thoroughly water-shrunk, after which from one to three entire conspicuous lines are painted lengthwise of the tent for the length of the full-length strips, and one line at right angles to longitudinal line or lines.

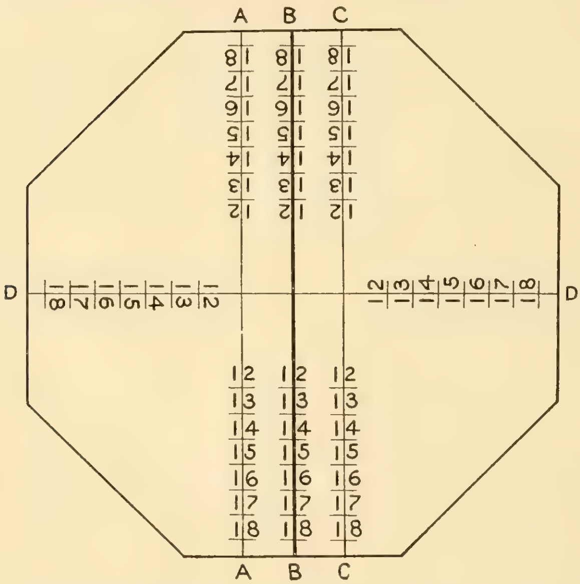


FIG. 6.—Diagram showing method of marking tents to aid in obtaining dimensions of inclosed space when covering tree: *AA*, *BB*, *CC*, parallel lines painted lengthwise with the strips of cloth from one "end" of the tent to the other; *DD*, cross-line passing through center of tent at right angles to other three. [Figures on lines *AA*, *BB*, and *CC* represent the distances in feet from the line *DD* and figures on *DD* represent distances from line *BB*. For the purposes of the diagram these distances are not proportional to the size of the tent.] (Original.)

For bell tents and sheet tents up to about 35 feet in diameter, one line running lengthwise of the strips will be sufficient, although three are preferable. For larger sheet tents three lines should always be made. The tent may be water-shrunk, if not already so, by allowing it to become wet with dew or other means, after which it should be thoroughly dried in the sun. The entire tent, or at least the central section of full-length strips, is spread flat on the ground, and the middle strip with the proper location for a median line is located. This line should be painted with a good quality of black paint[a] (flexible paint preferable) about 2½ or 3 inches wide. If three lines are

[a] Paints containing linseed oil should be avoided.

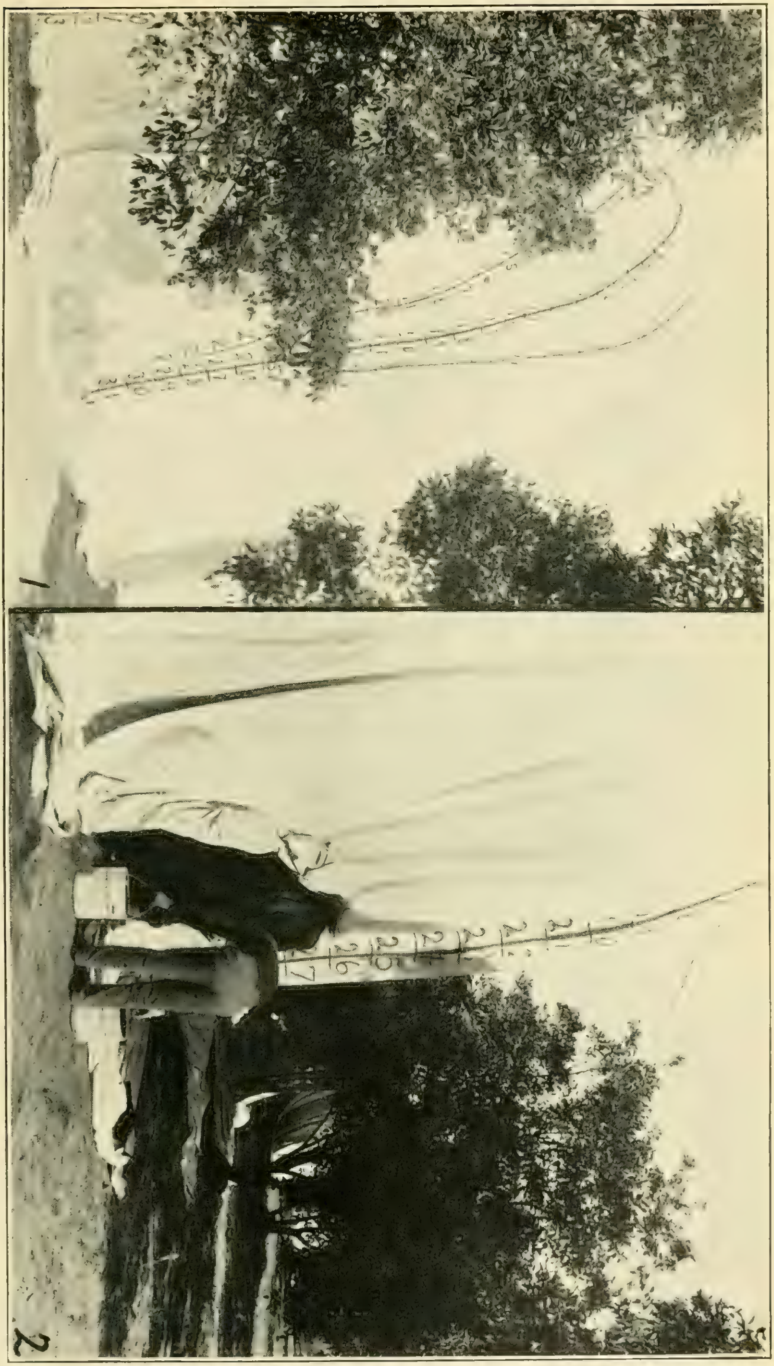


FIG. 1.—EIGHTY-FOOT TENT COVERING LARGE SEEDLING ORANGE TREE, SHOWING TENT GRADUATED FOR THE PURPOSE OF ENABLING OPERATORS TO USE DOSAGE TABLE GIVEN IN THE APPENDIX. FIG. 2.—CARRYING 5-GALLON CROCKS CONTAINING ACID AND WATER UNDER THE TENT, PREPARATORY TO INTRODUCING THE CYANID. (ORIGINAL.)

needed, another one is painted on each side of this line at a distance of about 36 inches for tents 60 feet or less in diameter and from 42 to 48 inches for tents of larger size. These two lines should not be more than 1 inch in width, so that they can be readily distinguished from the wider median line. The exact center of the tent is now located by measurement on the median line and the corresponding points on the two outside lines are marked. Taking into consideration the smallest tree that the tent probably will ever be used to cover, distances are measured on these three lines, in both directions from the center, so that parallel lines about 4 inches long, ½ inch wide, and 1 foot apart can be made across each longitudinal line, beginning 1 foot from the edge of the tent

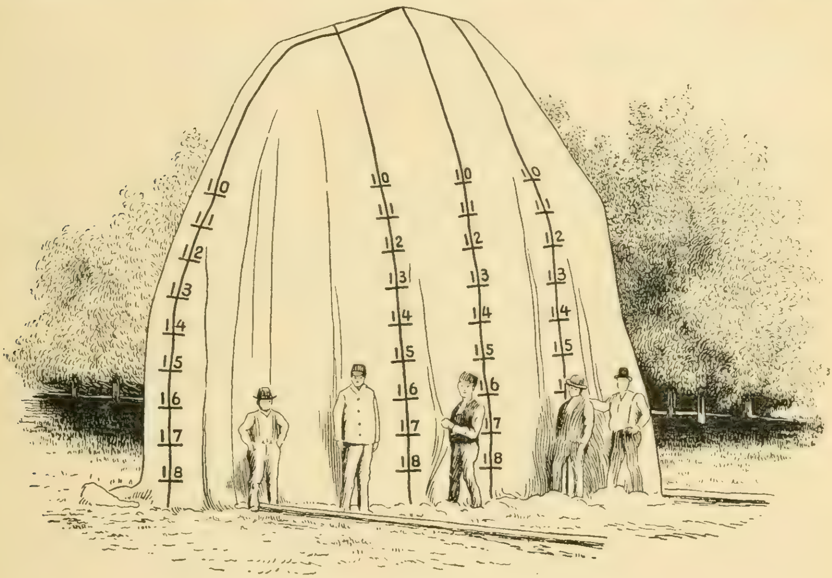


FIG. 7.—Tent marked to aid in estimating dosage, in position for fumigation. (Adapted from Marlatt.)

and making the lines in succession toward the center. After making a given number of these cross lines on each longitudinal line, the number in each case equal to the distance from the middle point to the cross line is painted on with conspicuous figures. (Pl. III, figs. 3, 4, 5, and 6; Pl. IV, fig. 1; Pl. VII, figs. 1 and 2.) If properly marked according to these directions, the corresponding cross lines on the three parallel longitudinal lines should be marked with the same number, as shown in figure 6. When the tent is exactly centered over a tree the reading at the ground on both sides of the tent will be the same. Ordinarily, however, when the tent is so placed that this line passes as nearly over the center of the tree as it is possible to estimate, the readings will differ by 2 or 3 feet, often more. As the tent should always be pulled lengthwise of the strips, the central line will most often lie over the center of the tree, and hence be most useful in obtaining the distance over from ground to ground. Frequently, however, this measurement of the tented tree can be best obtained by selecting for the purpose one or the other of the outside lines. The distance over the top in all cases is the sum of the two readings on the line selected. The fourth line, painted at right angles to the three running lengthwise, passing through the middle point of each, extending to the sides of the tent and marked with the distances corresponding to those on the first three lines, will be of advantage when a tree is so irregular in form that one line passing over the center of the tree seems to fail to give the measurement with sufficient accuracy. When it is necessary to use this line the tent can be readily pulled directly forward or backward whatever distance is necessary to bring this line as nearly as possible over the center of the tree, leaving the longitudinal line (previously selected as the one passing most nearly over the center) in the same relative position as before. The average of the readings on the two lines will give the desired dimension as nearly correct as is necessary. Measurements of a few such irregular trees will assist the operator's judgment until his experience is sufficient to enable him to estimate the allowance in ordinary cases when necessary. The tables appended, however, give a margin above the average requirements which will cover ordinary cases of variation from the regular forms.

When a single longitudinal line is used on the smaller sized tents this line can be readily brought to any desired position by pulling sidewise on the tent, without the risk of damage by ripping at the seams, as with the larger sizes. The lines, in addition to their usefulness in estimating the dosage, will be found of considerable assistance in locating the catch rings, and in other ways, when handling the tent.

Previously proposed schemes for marking tents to aid in estimating dosage.—The idea of marking the tents to aid in determining the dose is not a new one, for in California several years ago a tent was invented which was marked with concentric rings, at each of which a dose was indicated. This failed to take into consideration the variation in circumference of tented trees whose distance over is the same. Professor Woodworth has suggested a system of marking tents, concerning which he says: [a]

It consists in making a series of parallel lines near two opposite edges of the tent, which are so distanced from the center point that they shall correspond with the dosage of a tree of the average shape. Upon these lines will be placed numerals,

[a] Bul. 152, Cal. Agr. Exp. Sta., p. 15.

indicating the dose, the circumference in yards (paces), and the difference (that is, the amount the dose must be varied) should the distance around be more or less than the amount indicated for an average tent.

This suggestion in regard to the marking of tents with the dosage to obviate the use of printed tables seems to the writer to be of considerable value under some circumstances. One objection to the use of differentials in this manner is that the cubic capacity and dosage does not increase in direct proportion to the increase in circumference with a given distance over the top. To illustrate the method of marking the tents with the dosage, when desired, a tent measuring 30 feet over from ground to ground will serve as an example. The table in the appendix shows that for every 5 feet of difference in the measurement of the circumference of a tent measuring 30 feet over the top, the amount of cyanid is increased or decreased one-half ounce, or 0.1 ounce for each foot. With the figure 30 on the tent, we would place the dosage of a tented tree measuring 30 feet in circumference. The dosage called for by the table for a tent of this size (30 by 30) is 9½ ounces. Following this the differential, or 0.1 ounce, is placed. The entire directions for obtaining the dosage would read 30—9½—0.1. A tented tree measuring 30 feet over and 38 feet in circumference would require 9½ ounces plus 0.8 ounce or, for practical purposes, 10½ ounces. If the measurement was 30 feet over and 25 feet in circumference, the dosage would be 9½ less 0.5 ounce, or 9 ounces.

When tables are worked out in detail, as they should be where accurate work is desired, reference to them is undoubtedly by far the quickest and safest method under ordinary circumstances.

METHOD OF GENERATING THE GAS.

In order to permit of making the measurements of tents and estimating the dosage with the care hereafter recommended and with the least possible delay, it is sometimes advisable, in operations on a large scale, that the cyanid be weighed during the day or at other times when it is not advisable to fumigate, or, if done at night, that an additional helper be employed. Such a helper, in addition to weighing the cyanid, might look after the replenishing of the stock of cyanid and acid at the cart as needed and assist in measuring the tents and emptying the generating jars. The cyanid should be weighed up in lots of ½, 1, 2, 5, 10, and 20 ounces, put into paper bags of convenient size, and protected from dampness. When the tented trees all measure less than 34 feet over the top from ground to ground, the doses of 20 ounces each will not be required, and when measuring more than this the lots of one-half ounce may be dispensed with. At the cart, drag, or tray these bags of cyanid should be kept in separate boxes, or in separate compartments of a large box, and selected as needed to make up the proper dosage for the trees as they are fumigated. It has been the writer's experience that the better plan is to weigh up the chemicals in the field as fast as the dosage for the successive trees is determined. Three times as many ounces of water (liquid measure) as of cyanid is first poured into the jar. It is unnecessary to be exact in this measurement, and a long-handled dipper of 16 ounces or 1 pint capacity is preferable to the glass graduate. If, for example, 36 ounces of water are required, two and one-fourth dipperfuls are poured into the jar, dipping from the pail carried with the commissary tray. As many ounces of acid as cyanid to be used is measured in the graduate, being poured from one of the pitchers which are carried in one end of the commissary tray (Plate IV, fig. 1).

Another member of the crew in the meantime arranges for the proper dose of the cyanid and, with a lantern in hand when necessary, raises the edge of the tent while the one who measures the acid and water pours the acid into the jar containing the water, carries the cyanid and generating jar under the tent (Plate VII, fig. 2), and at arm's length empties in the cyanid. The jar should be placed about halfway between the base of the tree and the edge of the tent. For each 8 or 10 ounces of cyanid the generating jar should have a capacity of 1 gallon. For very large seedling trees two 3-gallon, 4-gallon, or even 5-gallon jars may sometimes be needed, while at other times one 3-gallon jar and one 2-gallon jar will be required for single trees, although to avoid errors it is preferable to divide the dose evenly between the jars when more than one are used. When two jars are used, they should be placed one on each side of the tree. The operator holds his breath, as soon as the cyanid is dropped into the generator, and as soon as he is outside the edge of the tent is dropped into place, while the violent boiling of the chemicals, as the gas is generated, can be distinctly heard for several minutes. The cyanid should be added as soon as possible after adding the acid, for the heat evolved by the acid and water at the time of mixing is necessary for the rapid generation of the gas. The man who measures the acid and generates the gas should have his hands protected by loose-fitting rubber gloves and should avoid being too close to the jar when pouring in the acid. He should never touch the tent while wearing the gloves unless they have been thoroughly rinsed in water.

WORK ROUTINE.

The systematic arrangement of the details of the procedure is of great importance in fumigation. The plans of work vary considerably with different fumigators, but it is the purpose in all cases to follow such work routine as will keep all hands constantly employed. In California from two to six men are employed in each outfit according to the size and number of the trees. For medium-sized trees requiring tents not larger than 44 feet in diameter, five men can work to advantage. This crew can handle 30 tents every forty-five minutes and can treat from 350 to 400 trees in a night's work of ten hours. For trees requiring larger tents, which are shifted by means of uprights, a crew of five or six men is needed to handle about 12 or 15 tents every forty-five minutes, or between 100 and 150 trees in a full night's work. This rapidity is attained when the trees are regularly set and properly spaced and when the schedules showing the dosage for each tree to be fumigated are prepared during the day, or when the dose is based upon the judgment of the fumigator after the tent has been placed in position. As has been stated, the plan of work commonly followed in California in treating scale insects, as far as the estimation of dosage is concerned, can not be recommended for use against the white fly in Florida. The method of estimating the dosage herein recommended at the most affects the schemes of routine previously followed in fumigating only by adding an extra man to the crew. One man can calculate the dosage faster than two men can weigh out the chemicals and generate the gas. The extra expense of an additional man is entirely negligible considering the increase in efficiency on the one hand and the check on unnecessary waste of the chemicals on the other.

Barrels of water should be placed during the day at convenient points in the grove, as should also carboys or large jugs containing the acid. The tents are taken to the end of the rows, unrolled, and placed in position for covering the first trees. The cart with its supply of acid and cyanid is located near the end of the row of tents, and everything is put in readiness to start work by sundown if the wind is not so strong as to interfere. Each man in the crew has definitely assigned duties. The men who handle the poles or derricks are commonly known in California as "tent pullers," or "tent men." These men, with their one or more assistants, proceed to pull each tent in succession over the first trees of the row. If one tree should be missing, the tent is left unused during the first period rather than to break the line by moving it at once to the second tree. As each tree is covered, each one of the tent men, after disconnecting his pole or derrick, walks halfway around the tent, pulling in the edges so that it will not spread out to inclose unnecessary space. A tent after being pulled in at the bottom is shown in Plate VI. After reaching the end of the row the tent men return to the cart or commissary tray and assist in generating the gas. As soon as the first tent is in position the foreman with a lantern in hand, except when the light from the moon is sufficient, notes the position of the tent with respect to the center of the tree, using as guides the lines heretofore described. The reading is made where the selected line touches the ground.

He notes on the scratch pad the first reading and paces around the tent, noting on the pad the reading on the opposite end of the selected line. Upon reaching the starting point the distance over and the circumference—as, for example, 38–44—are noted at once upon the diagram (fig. 3, *D;* figs. 4, 5). The dosage table is referred to and the amount of cyanid to be given is noted in the diagram below the figures noting the dimensions. The foreman or the man who determines the amount of chemicals then assists in measuring and introducing the chemicals, or if two other men are available for this work he proceeds to the next tree and determines the dosage as before.

The supply of water and chemicals for the set of tents is moved ahead as fast as the generating of the gas is started under each tree. The assistant, when working on the second set of trees, picks up the generating jars beneath the first trees recently fumigated and midway between the rows scoops out a hole with his foot or with a spade and buries the contents of the jar. The foreman should never trust any responsible part of the operation to an assistant whom he does not know to be reliable. He should thoroughly systematize the work so that no unnecessary hands will be employed while at the same time his entire outfit of tents will be utilized to the best advantage.

ESTIMATION OF TIME REQUIRED FOR FUMIGATION OF GROVE.

When two men can conveniently shift the tents, they can cover a tree, take the measurements, and generate the gas without difficulty in about five minutes when not hampered by irregularities in the location of trees. This means that two men should be able to handle 9 or 10 tents in forty-five minutes with the methods herein recommended. Allowing fifteen minutes each hour for rest and restocking of the commissary tray with chemicals, two men beginning at 4 p. m. could fumigate about 75 trees by midnight. Three men in the same time could easily fumigate 100 or 115 trees somewhat larger in size, or at the rate of 13 or 14 tents every hour. Four or five men should be able to fumigate each hour from 20 to 25 trees as large as can conveniently be covered by means of changing poles. When uprights are used a crew of six men, or possibly in some cases as many as eight, can work to best advantage. Such a crew should handle from 10 to 15 tents 50 feet in diameter, or larger, every hour, including time for rest and restocking cart or tray with the chemicals.

With three men attending to determining the dosage and generating the gas and two men shifting the tents, the trees being 12 to 15 feet high, the author with other agents of the Bureau in experimental work on one occasion fumigated 19 trees in thirty-five minutes. In one night a crew of six men have fumigated 221 budded trees varying from 12 to 16 feet in height. In this case certain irregularities in the plan of setting the grove prevented a much better record.

In undertaking the fumigation of a large grove the citrus growers should avoid underestimating the hindrance to the work through winds and rains. Fortunately during the season for fumigating in Florida there is comparatively little rainfall in ordinary years. In the central section of Florida winds at night will ordinarily interfere very little, but in sections near the coast interference from this source may be more frequent. From the middle of December until the middle of February it is well to make allowance for an average of two nights each week when fumigation work will have to be suspended.

In fumigating seedling trees 30 feet or more in height one could expect to fumigate from 300 to 400 trees a week with an outfit of 8 or 10 tents. In fumigating trees from 15 to 20 feet high with an outfit of 20 tents one could expect to fumigate from 800 to 1,000 trees a week. In the cases of both the large and the small trees these estimates can frequently be exceeded when conditions are favorable, but as the period for fumigating is so limited it is advisable to avoid underestimating the time required to complete the fumigation of a grove. In planning for the necessary equipment it is safe to calculate that with one tent for each 100 trees the work of fumigation can be completed in between ten and fourteen nights' work. In many cases it is necessary to have two complete outfits at work in the same grove when the work is started late in the season and there is danger of new growth appearing on the trees before one outfit could finish the grove.

METHODS OF COMPUTING APPROXIMATE DIMENSIONS AND CUBIC CONTENTS.

The dosage recommended in the table given in the appendix is based upon detailed records of 100 trees fumigated by the writer and his assistants during January and February, 1907. Heretofore tables of this kind have been based on the height and diameter of the trees, with the exception of one prepared by Prof. C. W. Woodworth, who first recommended a dosage system based on the dimensions of the tented trees. The two dimensions of practical importance are the circumference and the distance over the top from ground to ground. The method for obtaining these dimensions has been described. In Professor Woodworth's table of dosage referred to above, the amount of cyanid was directly proportional to the cubic contents. The table of dosage here recommended is based upon actual experience and is, as far as known to the writer, the first to take into consideration the effect of leakage. Tented trees are always more or less irregular and any attempt to calculate the volume of the space inclosed can give only approximate figures. A cylinder surmounted by a hemisphere is the regular figure that is nearest to the form of a tented tree. The leakage surface of a flat octagonal tent covering a tree obviously is not the same as the surface area of such a figure, but rather the area of a circle with a diameter equal to the distance over the top of the tent from ground to ground. To a certain extent the folds in a tent when in position over a tree reduce this surface, but this is a factor of little consequence, as it is present in all cases, and the portion of the tent folded so as to prevent all leakage represents only a small percentage of the whole. For practical purposes, therefore, the leakage surface is calculated from the mathematical formula 3.1416 multiplied by the square of the radius or πR^2. The approximate height of the tented tree can be calculated from the following formula, in which C represents the circumference of the tent at the base and O represents the distance over the top: $H = \frac{C/\pi}{2} + \frac{O - C/2}{2}$.

The diameter is found by dividing the circumference by 3.1416. The height and diameter having been obtained, the cubic contents of the regular figure mentioned can be calculated by the following formula: $\pi R^2 \left(H - \frac{R}{3}\right)$. The actual cubic inclosure of a tented tree will obviously always be more or less smaller than the regular figure to which this formula applies, although irregularities in shape will have a tendency to counteract one another.

DOSAGE REQUIREMENTS FOR THE WHITE FLY.

EXPERIMENTS WITH SHEET TENT.

Summary of results with regard to dosage.—In experiments to determine the dosage requirements for the white fly when using sheet tents, detailed records were made concerning each tree fumigated during the first season's work,[a] including every factor which might influence the results. The main objects in view in conducting the experiments were to determine the minimum dosage requirements for destroying the white fly larvæ and pupæ, the rate of leakage of the gas through the cloth, the effect of moisture on efficiency of the treatment, the effect of the treatment upon the foliage under various conditions of moisture, the margin as to dosage between effective treatment for the insect and danger to the tree, and the effect of different proportions of water and acid. Observations on other points, such as effect of wind, sunlight, condition of foliage as affected by drought, etc., were made as opportunity afforded. All the experiments were conducted between January 12 and March 1, 1907, inclusive, but observations as to results were continued for several weeks after the latter date. During this period practically

[a] The results of the experimental work during the winter of 1907–8 substantiate the conclusions derived from the work of the first season so far as the data up to this time completed show.

all the immature white flies were in the pupal stage. Of the many thousands of specimens examined in the course of the experiments, less than five were in earlier stages. The principal experiments were conducted in the grove at the laboratory in Orlando, Fla., but cooperative experiments were conducted on a larger scale in an extensive grove in the western portion of Orange County. The detailed records concerning the efficiency of fumigation against the white fly refer to experiments conducted at Orlando. A group of trees was selected for treatment on account of the comparative abundance of the live insects. As it was considered desirable to examine the insects both before and after treatment, leaves were selected at various distances from the ground, and in various sections of the tree, and the number of live and apparently normal pupæ was noted on a tag which was left attached to each leaf. After fumigation examinations were made at intervals of a few days until the appearance of the pupæ on the tagged leaves showed, beyond doubt, that the insects were dead or, if unaffected, until the evidences of normal vitality were unmistakable or the adult insects had emerged.

The acid used in the experiments, with the exception of experiments Nos. 45.37, 60.21, X.7, and X.8, was tested with a Beaumé hydrometer and found to be 66°, as guaranteed by the manufacturers. The potassium cyanid was guaranteed to be 99 per cent pure. A sample was analyzed in the Bureau of Chemistry of the Department of Agriculture and it was reported to contain 40.59 per cent cyanogen, a little more than 0.5 of 1 per cent more than that theoretically present in chemically pure potassium cyanid, the excess being due to a trace of sodium cyanid.

As has been previously stated, the sheet tent used was made of the brand of 8-ounce duck which is most used in California for fumigating tents. The tent was untreated but was thoroughly shrunk by exposure to heavy dews and therefore as tight as those ordinarily used.

A system of numbering the experiments was adopted which indicates the length of exposure and consecutive number of the tree treated for the particular duration of time. The number before the decimal point indicates this exposure for sixty minutes and less. Exposures ranging from one and a half to three hours are indicated by the letter X preceding the decimal point.

Table IV summarizes the data based upon the experiments of January and February, 1907, concerning dosage for the white fly, including for convenience the dosage called for by the tables found in the appendix.

TABLE IV.—*Summary of dosage experiments with sheet tent constructed of 8-ounce duck.*

Experiment No.	Measurements of tented tree.		Amount of cyanid used.	Per cent of white flies destroyed.	Amount of cyanid recommended in table given in appendix; 45 minutes' exposure.
	Distance over.	Circumference.			
	Feet.	*Feet.*	*Ounces.*		*Ounces.*
20.1	45	57	16½	91.9	29½
30.1	50	60	7	31	35½
30.2	44	58½	11	66	28
30.4	47	62	18	92	33
30.5	39	50	16½	98.6	20
30.6	46	56	20	71	29
30.7	40½	56	30	100	24
30.8	38	48	25¾	100	18½
40.1	44	53	5	31	25½
40.2	41½	59	10	84	26
40.3	42½	60	15	85	27
40.4	45	56	21	80	28½
40.6	39	54	17½	88	21
40.8	44½	58½	17¼	97	29½
40.9	43½	56	12	93	27
40.10	38	46	13½	95.7	17½
40.11	45½	63	25	99.2	32½
40.12	51½	64	30¾	98.4	41
40.13	44½	57	24	100	28
40.14	43½	54	26¼	100	26
40.15	37	48	21	100	18
40.18	43	54	32	100	25
40.20	43	60	32	100	27
40.21	47½	56	38	100	31
45.1	37	47	21	100	17½
45.3	47	51½	22	99.5	28
45.4	45	57½	23	100	28
45.5	46½	60½	26½	98.9	32
45.6	43½	56	22½	100	26½
45.7	50½	56	36	100	34
45.8	44½	58	27	100	28
45.9	36½	48	21	100	17
45.10	45½	67	35	100	34
45.12	34½	43	15¾	100	14
45.13	31½	38	11½	100	11½
45.15	40½	50	26¼	+99.6(?)	21
45.17	37	45	21	100	16½
45.19	31½	39	14¼	100	11½
45.20	33	50	12½	99.5	15
45.21	31	42	9	89.3	11
45.22	38	46	13¾	99.8	18
45.23	46½	56	29½	100	29½
45.24	34½	47	15½	100	15
45.25	48½	57	33½	100	32
45.26	33	46	13	100	14
45.27	46½	65	36½	+99.7(?)	34
45.28	46½	50	24½	99.5	26½
45.30	29½	30	6	100	9½
45.33	34½	36	10	100	14
45.34	40½	44	21	100	19½
45.35	40½	47	20	100	19½
45.36	45	50	20½	97.7	25
45.37	35	50	19¼	92	16½
50.1	44	58	23	66	28
50.2	39½	46½	28	100	19
50.5	52	56	37	100	35½
60.1	51	60½	30½	98.6	38
60.2	43	56	22	100	26½
60.4	44½	58	23½	100	29
60.5	38½	50	16½	100	20
60.6	33½	38	8½	97	13
60.7	38½	56	18	94	22½
60.19	41½	58½	27½	100	26½
60.20	29	37½	8½	66	10
60.21	41	55	25	97.6	24
X.1	43½	56	22½	96.7	26½
X.3	47½	54	28½	99.6	30
X.4	34	49	15	99.8	15½
X.5	47½	54	24½	99.7	30
X.6	45½	53	17¼	98.8	27½
X.7	49	62	40	[a] 99.8	37
X.8	52½	64	35½	[b] 94	42

[a] One pupa apparently alive 24 days after fumigating; 738 dead.
[b] 200 examined; 188 killed, 12 alive.

Deductions concerning effective dosage.—In formulating a definite table of dosage requirements from the above experiments the most significant results are those in which the amount of cyanid used was sufficient to destroy all but a very small percentage of the insects. Table V gives more complete data concerning the foregoing experiments, in which from 95 to 99.9 per cent of the insects were killed; also, for comparison, it gives the dosage called for by tables prepared by the author.

TABLE V.—*Data concerning dosage in those experiments in which 95 to 99.9 per cent of white flies were destroyed.*

Experiment No.	Measurements of tented tree.		Approximate capacity of inclosed space.	Approximate leakage surface	Ratio of leakage surface to cubic contents.	Amount cyanid used.	Rate: Number cubic feet per ounce cyanid.	Amount cyanid recommended in table given in appendix	Rate: Number cubic feet per ounce cyanid recommended.
	Distance over.	Circumference.							
	Feet.	*Feet.*	*Cu. ft.*	*Sq. ft.*		*Ounces.*		*Ounces.*	
30.5	39	50	2,448	1,075	1:2.28	16½	148	20	122
40.10	38	46	2,080	1,134	1:1.83	13½	154	17½	119
40.8	44½	58½	3,584	1,554	1:2.30	17¼	207	29	123
40.11	45½	63	4,290	1,625	1:2.65	25	171	32½	131
40.12	51½	64	5,338	2,082	1:2.56	30¾	174	41	130
45.20	33	50	1,862	855	1:2.17	12½	149	15	124
45.22	38	46	2,080	1,134	1:1.83	13½	154	17½	119
45.36	45	50	3,046	1,590	1:1.88	20½	148	25	122
45.28	46½	50	3,194	1,697	1:1.88	24½	130	26½	120
45.5	46½	60½	4,238	1,697	1:2.49	26½	160	32	132
45.3	47	50½	3,397	1,734	1:1.95	22	154	28	121
60.6	33½	38	1,297	881	1:1.47	8½	152	13	100
60.21	41	55	3,027	1,320	1:2.29	[a] 25	121	24	126
60.1	51	60½	4,867	2,042	1:2.38	30½	160	38	128
[b] X.4	34	49	1,890	908	1:2.08	15	126	15½	122
[c] X.1	43½	56	3,412	1,485	1:2.29	22½	156	26½	129
[d] X.6	45½	53	3,272	1,625	1:2.01	17¼	189	27½	119
[e] X.5	47½	54	3,713	1,771	1:2.09	24½	151	30	123
[f] X.3	47½	54	3,713	1,771	1:2.09	28½	130	30	123

[a] One of several trees fumigated on night of March 1, 1907. Unsatisfactory results supposed to be due to poor quality of acid.
[b] Exposure, 1 hour and 45 minutes.
[c] Exposure, 2 hours and 50 minutes.
[d] Exposure, 1 hour and 30 minutes.
[e] Exposure, 1 hour and 35 minutes.
[f] Exposure, 1 hour and 55 minutes.

For purposes of comparison with Table V, the data on the dosage experiments in which all of the insects were believed to have been killed in forty-five-minute exposures are given in Table VI, which, like the preceding, includes the rate and amount of dosage calculated according to the dosage recommendations hereinafter given.

TABLE VI.—*Data concerning dosage in those experiments in which 100 per cent of white flies were destroyed.*

Experiment No. (series 45).	Measurements of tented tree.		Approximate capacity of inclosed space.	Approximate leakage surface	Ratio of leakage surface to cubic contents.	Amount cyanid used.	Rate: Number cubic feet per ounce cyanid.	Amount cyanid recommended in table given in appendix	Rate: Number cubic feet per ounce cyanid recommended.
	Distance over.	Circumference.							
	Feet.	*Feet.*	*Cu. ft.*	*Sq. ft.*		*Ounces.*		*Ounces.*	
30	29½	30	735	683	1:1.08	6	118	9½	77
13	31	38	1,149	754	1:1.52	11½	100	11	104
19	31½	39	1,219	779	1:1.56	14¼	84	11½	106
26	33	46	1,656	855	1:1.93	13	127	14	118
33	34½	36	1,224	935	1:1.31	10	122	13	94
12	34½	43	1,620	935	1:1.73	15¾	103	14	116
24	34½	47	1,855	935	1:1.98	15½	119	15½	119
17	36½	45½	1,888	1,043	1:1.81	21	90	17	111
9	36½	48	2,049	1,043	1:1.96	21	98	17	120
1	37	47	2,075	1,075	1:1.93	21	99	17	122
34	40	44	2,092	1,256	1:1.66	21	100	18½	113
35	40	47	2,341	1,256	1:1.86	20	117	20	117
6	43½	56	3,412	1,482	1:2.35	22½	151	26½	129
8	44½	58	3,691	1,554	1:2.37	27	136	29½	125
4	45	57½	3,732	1,589	1:2.34	23	162	28½	131
10	45½	67	4,665	1,625	1:2.87	35	133	34½	132
23	46½	56	3,556	1,697	1:2.15	29½	124	30	118
25	48½	57	4,095	1,846	1:2.21	33½	122	33	124
7	50½	56	4,275	2,002	1:2.13	36	119	34	125

These tables show that with tents of 8-ounce duck and untreated with paint or sizing there is little or no advantage in exposures of more than 40 minutes. The results with exposures of 30 and 40 minutes compare favorably with those ranging from 45 minutes to 2 hours and 50 minutes. It is evident that the gas escapes rapidly and that in the course of a period of 30 to 40 minutes at the most the gas from a dosage of maximum utility is so diluted as to be practically ineffective. On the other hand, the table shows conclusively that the experiments afford no justification for reducing the dosage on account of lengthening the exposure from 45 to 60 minutes or longer. Everything considered, the writer adopted the 40-minute period of exposure as probably affording the greatest benefit from a given amount of cyanid.

As an aid in determining the rates of dosage which could be safely recommended for the various ratios of leakage surface to cubic contents, the experiments referred to in Table V were arranged in accordance with the ratio, and in each case the writer estimated the amount of potassium cyanid which it seemed evident would have been ample for the destruction of all the insects. The degree of success obtained with the amount of potassium cyanid actually used was taken into consideration in estimating the amount needed. The data thus arranged, together with calculations of the rate, or number of cubic feet of space per ounce of potassium cyanid, are given in Table VII.

TABLE VII.—*Study of dosage rates.*

Ratio of square feet in leakage surface to cubic feet of contents.	Amount of cyanid used.	Per cent of white flies destroyed.	Amount cyanid estimated as necessary for successful results.	Rate: Number cubic feet of space per ounce of cyanid.	
				Used.	Estimated as necessary.
	Ounces.		*Ounces.*		
1:2.65	25	99.2	27	171	159
1:2.56	30¾	98.4	34	174	157
1:2.49	26½	98.9	29	160	146
1:2.38	30½	98.6	33	160	144
1:2.30	17¼	97	20	207	179
1:2.29	25	97.6	28	127	108
1:2.28	16½	98.6	19	148	128
1:2.17	12½	99.5	14	149	133
1:2.09	24½	99.7	27	151	138
1:2.09	28½	99.6	30	130	124
1:2.08	15	99.8	16	126	118
1:2.01	17¼	98.8	20	189	163
1:1.95	22	99.5	24	154	141
1:1.88	24½	99.5	27	130	118
1:1.88	20½	97.7	24	148	127
1:1.83	13½	99.8	15	154	138
1:1.83	13½	95.7	17	146	122
1:1.47	8½	97	11	152	118

From a study of the data in the Table VII the writer concluded that for a ratio of 1:1.5 the cyanid should be used at a rate very near to 1 ounce to 110 cubic feet of space. Owing to the fact that in all cases tented trees include less inclosed space than would a regular figure which for purposes of approximate calculations has been considered as equivalent, this rate would be higher for a regularly shaped inclosure whose cubic contents could be definitely calculated. Probably 1 ounce to 100 cubic feet of space is nearer the actual rate which the experiments indicate is necessary with the ratio mentioned. This, however, is of little consequence in dealing with sheet tents, for only the comparative volumes and dosage rates for trees of different dimensions are required for practical purposes. Having decided upon the adoption of 1 ounce of potassium cyanid per 110 cubic feet of space with the ratio of 1:1.5, calculations were made for tents with different ratios up to 1:3.6. Professor Gossard reports[a] that 1 ounce to 170 cubic feet of space destroys all white fly pupæ in an air-tight fumigatorium. Considering that this rate is approximately correct, an equivalent rate for the volume inclosed by a sheet tent covering a tree would be more than 170 cubic feet in the ideal form of inclosure upon which the calculations are based. Experiments numbered X.3 and X.4, however, show that a rate not less than 1 ounce for 126 cubic feet of space should be used when the ratio is 1:2. When the ratio is increased from 1:1.5 to 1: infinity[b] and the rate of dosage for this latter ratio is considered as 1 ounce

[a] Fla. Exp. Sta. Bul. 67, p. 652.

[b] It is evident that if the number of cubic feet of space were infinitely greater than the number of square feet of leakage surface, the rate of dosage required for an air-tight fumigatorium would be sufficient.

for 170 cubic feet of space, all of the rates are more or less greater than those used in the experiments in which from 95 per cent to 99.9 per cent of the insects were killed. It is evident that the increase in number of cubic feet per ounce of potassium cyanid from 110 to 170 must be calculated at a rate which is in direct proportion to the percentage of increase in cubic contents. The method employed in these calculations is shown in Table VIII, which gives the figures with the ratios ranging from 1:1.0 up to 1:3.6.

TABLE VIII.—*Rates of dosage as affected by ratio of number of square feet in surface to the number of cubic feet in volume.*

Ratio.	Per cent of increase in cubic contents.	Number of cubic feet per ounce cyanid.	Difference between number cubic feet per ounce and 170.	Increase in number cubic feet per ounce cyanid.	Ratio.	Per cent of increase in cubic contents.	Number of cubic feet per ounce cyanid.	Difference between number cubic feet per ounce and 170.	Increase in number cubic feet per ounce cyanid.
1:1	....	76.8	93.2	....	1:2.4	4.34	133.5	36.5	1.7
1:1.1	10	86.1	83.9	9.3	1:2.5	4.16	135	35	1.5
1:1.2	9.09	93.7	76.3	7.6	1:2.6	4	136.4	33.6	1.4
1:1.3	8.33	100.1	69.9	6.4	1:2.7	3.85	137.7	32.3	1.3
1:1.4	7.69	105.4	64.6	5.3	1:2.8	3.7	138.9	31.1	1.2
1:1.5	7.14	110	60	4.6	1:2.9	3.6	140	30	1.1
1:1.6	6.66	114	56	4	1:3.0	3.44	141	29	1.03
1:1.7	6.25	117.5	52.5	3.5	1:3.1	3.33	142	28	.97
1:1.8	5.88	120.6	49.4	3.1	1:3.2	3.26	142.9	27.1	.91
1:1.9	5.55	123.3	46.7	2.7	1:3.3	3.12	143.8	26	.85
1:2.0	5.26	125.8	44.2	2.5	1:3.4	3.03	144.5	25.4	.79
1:2.1	5	128	42	2.2	1:3.5	2.94	145.3	24.7	.75
1:2.2	4.76	130	40	2	1:3.6	2.86	146	24	.71
1:2.3	4.54	131.8	38.2	1.8					

In Table VIII the number of cubic feet of space per ounce of potassium cyanid increases toward 170, representing the rate when the ratio is 1 to infinity, and the dosage increases in rate (= decrease in the number of cubic feet per ounce of potassium cyanid) as the units of cubic contents become infinitely small in number as compared with the units of square measure of leakage surface. Using the above rates as a basis, the doses for trees measuring from 10 to 76 feet over the top have been calculated. The dimensions of the tented trees and volumes of the inclosed spaces have been calculated in accordance with the formulæ given in the preceding pages. Table IX gives the original calculations, while in the appendix the recommended doses alone are given, in a form more convenient for practical use in the field.

TABLE IX.—*Recommended dosage, with 45-minute exposures.*

Measurements of tented trees. Distance over.	Measurements of tented trees. Circumference.	Area of leakage surface.	Height of regular figure with foregoing measurements.	Diameter of regular figure with foregoing measurements.	Volume.	Ratio of leakage surface to cubic contents.	Rate of dosage, number cubic feet space per ounce cyanid	Amount of cyanid recommended.
Feet.	*Feet.*	*Sq. feet.*	*Feet.*	*Feet.*	*Cu. feet.*			*Ounces.*
10	15	78	3.6	4.7	48	1:0.61	....	1.0
	20	78	3.2	6.4	69	1:0.89	....	1.0
12	15	113	4.6	4.8	65	1:0.57	....	2.0
	20	113	4.2	6.4	101	1:0.89	....	2.0
14	15	154	5.6	4.8	85	1:0.55	....	2.5
	20	154	5.2	6.4	133	1:0.86	....	2.5
	25	154	4.7	8.0	171	1:1.11	76	2.5
16	20	201	6.2	6.4	165	1:0.82	62	3.0
	25	201	5.7	8.0	221	1:1.10	88	3.0
	30	201	5.3	9.5	276	1:1.37	100	3.0
18	20	254	7.2	6.4	197	1:0.77	56	4.0
	25	254	6.7	8.0	271	1:1.06	74	4.0
	30	254	6.3	9.5	347	1:1.36	102	4.0
	35	254	5.8	11.1	406	1:1.60	114	4.0
20	20	314	8.2	6.4	229	1:0.73	54	4.2
	25	314	7.7	8.0	321	1:1.02	76	4.2
	30	314	7.3	9.5	418	1:1.33	100	4.2
	35	314	6.8	11.1	500	1:1.59	112	4.4
22	25	380	8.7	8.0	372	1:0.97	75	4.9
	30	380	8.3	9.5	489	1:1.28	96	5.1
	35	380	7.8	11.1	594	1:1.56	111	5.3
	40	380	7.4	12.7	670	1:1.78	118	5.9
24	30	452	9.3	9.5	550	1:1.21	93	5.9
	35	452	8.8	11.1	688	1:1.52	110	6.2
	40	452	8.4	12.7	797	1:1.76	117	6.8
	45	452	7.9	14.3	927	1:2.05	128	7.2
26	30	531	10.3	9.5	621	1:1.17	89	7.0
	35	531	9.8	11.1	782	1:1.47	107	7.3
	40	531	9.4	12.7	924	1:1.74	118	7.8
	45	531	8.9	14.3	1,046	1:1.97	124	8.4
28	30	615	11.3	9.5	692	1:1.12	86	8.1
	35	615	10.8	11.1	876	1:1.42	105	8.3
	40	615	10.4	12.7	1,051	1:1.70	117	8.9
	45	615	9.9	14.3	1,206	1:1.96	124	9.7
30	30	707	12.3	9.5	763	1:1.08	80	9.0
	35	707	11.8	11.1	970	1:1.37	100	9.7
	40	707	11.4	12.7	1,178	1:1.66	114	10.3
	45	707	10.9	14.3	1,364	1:1.93	123	11.1
32	30	804	13.3	9.5	834	1:1.03	79	10.5
	35	804	12.8	11.1	1,067	1:1.32	100	10.7
	40	804	12.4	12.7	1,305	1:1.62	114	11.4
	45	804	11.9	14.3	1,527	1:1.90	123	12.4
	50	804	11.5	15.9	1,750	1:2.17	129	13.6
34	30	908	14.3	9.5	906	1:1.00	76	4.9
	35	908	13.8	11.1	1,161	1:1.28	95	12.0
	40	908	13.4	12.7	1,433	1:1.58	112	12.8
	45	908	12.9	14.3	1,684	1:1.85	121	13.9
	50	908	12.5	15.9	1,951	1:2.14	128	15.2
36	35	1,018	14.8	11.1	1,265	1:1.24	95	13.3
	40	1,018	14.4	12.7	1,560	1:1.53	110	14.2
	45	1,018	13.9	14.3	1,844	1:1.81	120	15.3
	50	1,018	13.4	15.9	2,149	1:2.11	128	16.7
	55	1,018	13.0	17.5	2,428	1:2.38	132	18.4
38	35	1,134	15.8	11.1	1,360	1:1.20	93	14.6
	40	1,134	15.4	12.7	1,688	1:1.48	107	15.7
	45	1,134	14.9	14.3	2,005	1:1.76	118	17.0
	50	1,134	14.4	15.9	2,348	1:2.07	126	18.7
	55	1,134	14.0	17.5	2,668	1:2.35	132	20.2
40	40	1,256	16.4	12.7	1,816	1:1.44	106	17.0
	45	1,256	15.9	14.3	2,165	1:1.72	117	18.5
	50	1,256	15.4	15.9	2,546	1:2.02	125	20.3
	55	1,256	15.0	17.5	2,909	1:2.31	131	22.2
	60	1,256	14.5	19.1	3,256	1:2.59	135	24.1
42	40	1,385	17.4	12.7	1,943	1:1.40	105	18.5
	45	1,385	16.9	14.3	2,326	1:1.68	115	20.2
	50	1,385	16.4	15.9	2,745	1:1.98	124	22.1
	55	1,385	16.0	17.5	3,149	1:2.27	130	24.2
	60	1,385	15.5	19.1	3,542	1:2.55	135	26.2
44	45	1,520	17.9	14.3	2,486	1:1.63	114	21.8
	50	1,520	17.4	15.9	2,944	1:1.93	123	23.9
	55	1,520	17.0	17.5	3,389	1:2.22	130	26.1
	60	1,520	16.5	19.1	3,828	1:2.52	135	28.3
	65	1,520	16.1	20.7	4,254	1:2.80	138	30.8

TABLE IX.—*Recommended dosage, with 45-minute exposures*—Continued.

Measurements of tented trees. Distance over.	Measurements of tented trees. Circumference.	Area of leakage surface.	Height of regular figure with foregoing measurements.	Diameter of regular figure with foregoing measurements.	Volume.	Ratio of leakage surface to cubic contents.	Rate of dosage, number cubic feet space per ounce cyanid.	Amount of cyanid recommended.
Feet.	*Feet.*	*Sq. feet.*	*Feet.*	*Feet.*	*Cu. feet.*			*Ounces.*
46	50	1,662	18.4	15.9	3,133	1:1.88	121	25.9
	55	1,662	17.9	17.5	3,630	1:2.18	129	28.1
	60	1,662	17.5	19.1	4,115	1:2.47	134	30.7
	65	1,662	17.0	20.7	4,591	1:2.76	138	33.2
	70	1,662	16.6	22.3	5,038	1:3.03	141	35.7
48	50	1,810	19.4	15.9	3,332	1:1.84	121	27.5
	55	1,810	18.9	17.5	3,870	1:2.13	128	30.2
	60	1,810	18.5	19.1	4,401	1:2.43	133	33.1
	65	1,810	18.0	20.7	4,927	1:2.72	137	35.9
	70	1,810	17.6	22.3	5,428	1:3.00	141	38.5
50	55	1,964	19.9	17.5	4,111	1:2.09	127	32.4
	60	1,964	19.5	19.1	4,687	1:2.38	132	35.5
	65	1,964	19.0	20.7	5,264	1:2.63	136	38.7
	70	1,964	18.6	22.3	5,828	1:2.96	140	41.6
	75	1,964	18.2	23.9	6,358	1:3.24	142	44.7
52	55	2,123	20.9	17.5	4,351	1:2.05	126	34.5
	60	2,123	20.5	19.1	4,974	1:2.34	132	37.6
	65	2,123	20.0	20.7	5,600	1:2.63	136	41.1
	70	2,123	19.6	22.3	6,217	1:2.92	140	44.4
	75	2,123	19.2	23.9	6,805	1:3.20	142	47.9
54	55	2,289	21.9	17.5	4,591	1:2.00	125	36.7
	60	2,289	21.5	19.1	5,261	1:2.30	131	40.1
	65	2,289	21.0	20.7	5,936	1:2.60	136	43.6
	70	2,289	20.6	22.3	6,607	1:2.88	138	47.8
	75	2,289	20.2	23.9	7,252	1:3.16	142	51.1
56	60	2,462	22.5	19.1	5,547	1:2.25	130	42.6
	65	2,462	22.0	20.7	6,273	1:2.54	135	46.4
	70	2,462	21.6	22.3	6,997	1:2.84	138	50.7
	75	2,462	21.2	23.9	7,700	1:3.12	142	54.2
	80	2,462	20.8	25.5	8,459	1:3.43	144	58.7
58	60	2,641	23.5	19.1	5,834	1:2.20	130	44.8
	65	2,641	23.0	20.7	6,609	1:2.50	135	48.8
	70	2,641	22.6	22.3	7,396	1:2.80	138	53.6
	75	2,641	22.2	23.9	8,147	1:3.09	141	57.7
	80	2,641	21.8	25.5	8,971	1:3.39	144	62.3
60	60	2,826	24.5	19.1	6,120	1:2.16	128	47.8
	65	2,826	24.0	20.7	6,945	1:2.45	134	51.8
	70	2,826	23.6	22.3	7,786	1:2.75	138	56.4
	75	2,826	23.2	23.9	8,595	1:3.04	141	60.9
	80	2,826	22.8	25.5	9,483	1:3.35	144	65.4
62	60	3,018	25.5	19.1	6,406	1:2.12	128	50.0
	65	3,018	25.0	20.7	7,282	1:2.41	133	54.7
	70	3,018	24.6	22.3	8,176	1:2.71	137	59.6
	75	3,018	24.2	23.9	9,042	1:3.00	141	64.1
	80	3,018	23.8	25.5	9,995	1:3.31	143	69.2
64	60	3,215	26.5	19.1	6,693	1:2.08	126	53.1
	65	3,215	26.0	20.7	7,618	1:2.37	132	57.7
	70	3,215	25.6	22.3	8,565	1:2.66	136	63.0
	75	3,215	25.2	23.9	9,489	1:2.95	140	67.7
	80	3,215	24.8	25.5	10,507	1:3.26	143	73.4
66	60	3,419	27.5	19.1	6,979	1:2.04	126	55.4
	65	3,419	27.0	20.7	7,955	1:2.33	131	60.7
	70	3,419	26.6	22.3	8,955	1:2.61	134	66.8
	75	3,419	26.2	23.9	9,937	1:2.90	140	70.9
	80	3,419	25.8	25.5	11,019	1:3.22	142	77.6
	85	3,419	25.3	27.1	11,939	1:3.49	144	82.9
68	60	3,630	28.5	19.1	7,266	1:2.00	125	58.1
	65	3,630	28.0	20.7	8,290	1:2.28	130	63.7
	70	3,630	27.6	22.3	9,345	1:2.57	135	69.2
	75	3,630	27.2	23.9	10,384	1:2.86	139	74.6
	80	3,630	26.8	25.5	11,531	1:3.17	142	81.1
	85	3,630	26.3	27.1	12,513	1:3.45	144	87.5
70	60	3,848	29.5	19.1	7,552	1:1.96	123	61.4
	65	3,848	29.0	20.7	8,627	1:2.24	130	66.3
	70	3,848	28.6	22.3	9,734	1:2.53	135	72.1
	75	3,848	28.2	23.9	10,831	1:2.81	138	78.5
	80	3,848	27.8	25.5	12,043	1:3.10	142	84.8
	85	3,848	27.3	27.1	13,088	1:3.40	144	90.9
72	60	4,069	30.5	19.1	7,838	1:1.92	123	63.7
	65	4,069	30.0	20.7	8,963	1:2.20	130	68.9
	70	4,069	29.6	22.3	10,124	1:2.49	134	75.5
	75	4,069	29.2	23.9	11,278	1:2.77	137	82.3
	80	4,069	28.8	25.5	12,555	1:3.08	141	89.0
	85	4,069	28.3	27.0	13,662	1:3.35	144	94.8
	90	4,069	27.8	28.6	14,829	1:3.64	146	101.5

TABLE IX.—*Recommended dosage, with 45-minute exposures*—Continued.

Measurements of tented trees. Distance over.	Measurements of tented trees. Circumference.	Area of leakage surface.	Height of regular figure with foregoing measurements.	Diameter of regular figure with foregoing measurements.	Volume.	Ratio of leakage surface to cubic contents.	Rate of dosage, number cubic feet space per ounce cyanid.	Amount of cyanid recommended.
Feet.	*Feet.*	*Sq. feet.*	*Feet.*	*Feet.*	*Cu. feet.*			*Ounces.*
74	60	4,299	31.5	19.1	8,125	1:1.89	121	67.1
	65	4,299	31.0	20.7	9,300	1:2.18	129	71.3
	70	4,299	30.6	22.3	10,513	1:2.45	134	78.4
	75	4,299	30.2	23.9	11,726	1:2.72	137	85.6
	80	4,299	29.8	25.5	13,067	1:3.03	141	92.7
	85	4,299	29.3	27.0	14,237	1:3.31	143	99.5
	90	4.299	28.8	28.6	15,471	1:3.60	146	106.0
76	60	4,534	32.5	19.1	8,411	1:1.85	120	70.0
	65	4,534	32.0	20.7	9,635	1:2.12	128	75.2
	70	4,534	31.6	22.3	10,903	1:2.40	133	82.0
	75	4,534	31.2	23.9	12,173	1:2.66	136	89.4
	80	4,534	30.8	25.5	13,579	1:2.99	140	97.0
	85	4,534	30.3	27.0	14,812	1:3.26	143	103.5
	90	4,534	29.8	28.6	16,113	1.3.55	145	111.1

EXPERIMENTS WITH BELL OR HOOP TENT.

The bell or hoop tent used in these experiments was one constructed of 6½-ounce drill of the brand most commonly used in California. Owing to the form of the tent the leakage surface is far less in proportion to the volume than in the sheet tent. The data concerning the experiments and the recommended dosage based upon the experiments with the sheet tent are given in Table X.

TABLE X.—*Experiments in fumigation with bell-shaped tent of 6½-ounce drill.*

Experiment No.	Measurements of tented trees. Distance over.	Measurements of tented trees. Circumference.	Amount of cyanid used.	Number of white flies under observation.	Per cent of white flies killed.	Amount of cyanid recommended in table for 45 minutes' exposure.
	Feet.	*Feet.*	*Ounces.*			*Ounces.*
30.3	28½	35	4	555	88	9
40.5	27	38	4	138	88	8½
40.7	33½	38	8½	132	80	13
40.16	20	23	4	300	100	4½
40.17	25½	27	7	476	100	7
40.19	24	20	4	209	100	5½
40.22	20	22	2	162	97.4	4½
45.2	28	29	7	427	100	8½
45.11	26	31½	4½	284	100	7½
45.14	31	35	10¾	289	100	10½
45.16	27½	29	6¾	431	100	8½
45.18	27	34½	9¼	595	100	8
45.29	29½	30	6	530	100	9½
45.31	23	24	3¼	376	98.7	6
50.3	24½	31½	4	128	97.6	7
50.4	34½	37	8½	990	100	14
60.8	26	31	4½	42	85.7	7½
X.2	33	35	11	200	100	12½

In these experiments a dosage sufficient to destroy all pupæ was used in eleven instances. The total amount of cyanid used in the eleven experiments was 78¾ ounces, whereas the doses recommended in the tables, based upon the experiments with the sheet tents of 8-ounce duck, together amounted to 96 ounces. The average of the amounts used in the eleven tests was 7.2 as against 8.7 recommended in the tables. It is evident from the results summarized in the foregoing table that prolongation of the period of exposure beyond 40 minutes produces no noticeable increase in effectiveness. It is also evident that the dosage recommended for use with sheet tents of a good quality of 8-ounce duck is ample for bell tents of a good quality of 6½-ounce drill. The smaller amount of leakage surface with bell tents as compared with sheet tents may be entirely responsible for the apparently wide margin between the recommended dosage and the dosage actually required for efficiency, but it seems safe to conclude that the 6½-ounce drill used in the bell tent held the gas approximately as well as the 8-ounce duck, the difference in leakage surface considered.

MISCELLANEOUS EXPERIMENTS AND OBSERVATIONS.

APPEARANCE OF LARVÆ AND PUPÆ OF THE WHITE FLY WHEN DESTROYED BY FUMIGATION.

The opportunities for studying the efficiency of the gas against citrus pests are far superior with the white fly as compared with the true scale insects. While it requires considerable skill in the examinations, the vital conditions of the larvæ and pupæ, both before and after treatment, can be recognized with practical certainty without removing the specimens from the leaves. When in a normal condition the insects in the stages mentioned appear green, owing to their translucence, and paired yellowish spots, due to internal organs, are sometimes visible in the abdominal region. As the pupa reaches maturity the reddish eyes of the adult become conspicuous and the location of the developing adult wings is indicated by whitish patches on either side of the body. When destroyed by fumigation with hydrocyanic-acid gas the larvæ and pupæ usually turn more or less brownish in the course of a few days. This brownish discoloration is most pronounced along the middle of the body. Frequently, however, two or three weeks may elapse before they can be positively determined as dead. In the first examinations made by the author, pupæ on fumigated trees were classed as alive, doubtful, and dead. It was afterwards determined that in practically every case those classed as doubtful were in reality dead. Examinations under a compound microscope were found to be of some assistance at times, but on the whole unsatisfactory. In such cases movements of the internal organs furnish positive proof that the insect is alive, but when these movements can not be detected there may still be doubt concerning the condition of the specimen unless granulation or discoloration of the body contents is evident. The most satisfactory method of observing the results of fumigation is to examine the insects with a hand lens of 1 or 1½ inch focal distance without disturbing the insect or detaching the leaf from the tree. String tags attached to leaves upon which are specimens classed as doubtful will enable examinations of such specimens from time to time until their condition is positively determined. A careful examination of normal specimens and direct comparisons of these with those on leaves of fumigated trees will assist in the ready identification of the dead insects.

DENSITY OF THE GAS AT VARIOUS HEIGHTS ABOVE THE GROUND.

It is natural to presume that owing to the fact that hydrocyanic-acid gas is lighter than air, its density during the process of fumigation is greater toward the top of the tree. In four of the nine observations on the comparative effect of the gas at different heights above ground the results of this variation in density are not evident. In the other five observations the results are quite striking. In the six experiments in which observations were made 10 feet or more from the ground, the average percentage of insects killed up to 6 feet above the ground was 64, while from 10 to 18 feet above ground the average percentage killed was 71. The data concerning the effectiveness of the gas at various distances from the ground is summarized in Table XI.

TABLE XI.—*Efficiency of gas as affected by height above ground.*

Experiment No.	Distance above ground.	Number of white fly pupæ examined.	Per cent killed.	Experiment No.	Distance above ground.	Number of white fly pupæ examined.	Per cent killed.
	Feet.				*Feet.*		
30.4	4–6	427	89	30.1	4–6	74	21
	14–15	244	98.3		12–14	909	36
	18	120	100	40.3	4–6	822	80
20.1	4–6	687	91.9		12–14	445	90.8
	12–14	1,000	90.8	30.3	2	396	92.8
20.7	4–5½	222	77		3½–7	159	78
	10	306	60	40.7	2	93	80.6
40.12	2	112	64		4–6	139	79.2
	3½–5	728	98.4				
	4–6	541	26.4				
	14–16	136	50				

The results show that when examining for the results of fumigation, the most significant effects are those within a few feet of the ground. The observations concerning the results of the experiments upon which the recommendations in this bulletin are based were made in all cases within 7 feet of the ground, and included examinations of insects on leaves closest to the ground in all cases.

EFFECT OF FUMIGATION ON THE TREES.

During the months of December, January, and February, until the appearance of the new spring growth, fumigation for the white fly with the dosage herein recommended will rarely occasion appreciable injury to orange trees and apparently never to tangerine and grapefruit trees. The liability of injuring trees through the emptying of the contents of the jars after fumigation close to or upon the base of the trees will be referred to under the subject of precautions. The injury to orange trees from the gas itself has never in the writer's experience been sufficient to offset the benefits of destroying the white fly and scale insect pests. Nevertheless the subject is one of considerable importance. The experiments conducted in January and February, 1907, demonstrated the practicability of destroying the white fly with hydrocyanic-acid gas without injury to citrus trees.

The fumigation of nearly 4,000 trees in the winter of 1907–8 has greatly extended our knowledge of the effect of fumigation upon the trees, but there remain several unsolved problems in this connection which it is hoped will be elucidated by future experience. The work of fumigating a grove should be completed if possible before the new growth appears in the spring. Under certain temperature conditions successful fumigations may occasion no injury to new growth, but there is danger of destroying the first spring shoots which normally produce the greater part of the blooms. When affected by the gas new shoots wilt and turn dark, appearing as though affected by frost.

Under certain conditions there is more or less shedding of the old leaves following fumigation. The loss of 10 or 15 per cent of the old foliage can not be considered an injury, inasmuch as even more than this proportion is usually shed during the winter or in the spring. In fact, it has been demonstrated by experiments conducted by Mr. Yothers and the writer in February, 1908, that the leaves shed by fumigation when the percentage of the whole does not exceed 15 per cent are among the leaves which would normally drop in the course of a few weeks.

In the experiments with the sheet tent of 8-ounce duck summarized in Table IV, the most extensive shedding occurred in experiments 40.14. In this it was estimated that about 50 per cent of the leaves were shed. The tree was fumigated on January 29, beginning at 4.07 p. m., about one-half hour before sunset. No shedding was observed until the morning of February 2, when it was estimated that from 15 to 20 per cent of the leaves dropped. On February 4 it was estimated that 50 per cent of the leaves had fallen, after which date the amount of the shedding was inappreciable. The winged petioles of the leaves remained attached to the tree in most cases and the fallen leaf blades showed distinct brownish areas due to burning by the gas. The tree consisted of five stems growing from the roots of a tree frozen to the ground in 1895. One of these stems was affected by foot rot or *mal-di-gomma*, and the defoliation of this was nearly complete, materially increasing the percentage of shedding from the tree as a whole. This tree was observed in full bloom on April 4, and ten months after the treatment appeared as vigorous as any tree in the grove and bore more than the average crop of fruit. In the experiments with the bell tent of 6½-ounce drill, shedding of consequence occurred only in the case of experiment X.2. This tree was fumigated on January 29, beginning at 4.41 and ending at 7.50 p. m. It was estimated that the shedding amounted to about 30 per cent in this case.

In experiment 45.36 the exposure began at 3.07 p. m. in bright sunlight with the temperature at 75° F. The tent had been in position for thirty minutes preceding the introduction of the chemicals, and the inside temperature was 4½° higher at the beginning than the outside temperature mentioned above. The tent was in direct sunlight during the entire forty-five minutes of exposure, and doubtless the inside temperature rose to 82° or 83°. As shown in Table IV, the amount of potassium cyanid used was 4½ ounces less than the amount recommended in the table given in the appendix. The leaves were curled as a result of drought at the time of the fumigation and no shedding of leaves or injury of any kind to the tree could be detected by subsequent examinations.

An overdose is indicated by the scorching of the foliage on entire twigs. This is more likely to occur near the tops of the trees. In such cases several twigs, each 6 inches or a foot in length, may be entirely killed, the leaves, instead of dropping within a few days, turning brown and remaining attached to the dead twig. This is not necessarily accompanied by excessive shedding of the foliage. The physiological condition of the trees seems to have a marked effect on their liability to shed foliage. Vigorous trees are less susceptible than weak, poorly nourished ones. Trees in the same grove but growing under different conditions as regards the nature of the soil and the amount of soil moisture show differences in this respect. In most groves trees will not shed leaves excessively if the dosage is increased 25 per cent above the recommended amounts. Frequently there will be no shedding at all following such a course. In other citrus groves the recommended dose is as large as the trees will stand without shedding to an injurious extent.

The likelihood of damaging citrus fruits by fumigation is such that it is strongly advisable to pick the crop before starting to fumigate. In January, 1908, many seedling trees were fumigated which held from five to eight boxes of oranges per tree, without any injury whatever following the treatment. In other cases a small percentage of the fruit developed sunken areas or "pits" which turned dark and ruined the affected fruit for shipping purposes. Fumigation in midwinter, using the dosage table given in the appendix, does not seem to affect the fruit of Hart's Lake, Lamb's Summer, or Valencia varieties. Grapefruits are slightly susceptible to this injury, while tangerines appear not at all susceptible, although considerable shedding of the fruit occurred in one instance when the recommended dosage was doubled.

SUGGESTIONS FOR THE FUMIGATION OF SMALL TREES.

IN THE GROVE.

In discussing the style of fumigating tents desirable for use against the white fly the author has referred to the advantages of the use of box covers for small trees. In many cases complete defoliation of the trees during the winter months would be the best method of checking the pest, but fumigation is preferable under most circumstances. The dosage with box covers will depend upon the tightness of the cloth used. It has been recommended that the cloth be made as nearly air-tight as possible by means of paint, or that air-tight oilcloth be used. The rate of dosage can be readily determined by means of a series of tests, beginning with 1 ounce of potassium cyanid for each 170 cubic feet of space (0.00588 ounce per cubic foot) and decreasing the number of cubic feet per ounce 10 feet for each experiment until the results are satisfactory and uniform. No experiments have thus far been conducted by the author along these lines, but it is expected that in the course of the investigations of the white fly now under way in Florida this phase of white fly control will be given consideration.

IN THE NURSERY.

Several square yards, including many trees, can be covered in the nursery by a single tent. If the cloth is unpainted, the dosage for a first trial can be calculated by first determining the ratio of the leakage surface to the cubic contents and referring to Table VIII in this bulletin, where the recommended rate of dosage will be found for the various ratios. The results of the preliminary tests should be carefully observed before fumigating on a large scale, in order that the rate of dosage may be adjusted to suit the tightness of the cloth used as a cover.

NURSERY STOCK FOR SHIPMENT.

Prof. H. A. Gossard, formerly of the Florida experiment station, has determined that in an air-tight fumigatorium 1 ounce of potassium cyanid for each 170 cubic feet of space[a] is sufficient to destroy all

[a] "One gram to 6 cubic feet of space," he reports, "seemed sufficient to kill everything, but to make the dose more certain 1 gram to $5\frac{3}{4}$ cubic feet was adopted as the standard dose and has been repeatedly tried, always giving the uniform result of killing all larvæ (pupæ) and adults."—Bul. 67, Fla. Exp. Sta., p. 652. One ounce is equal to 28.35 grams, from which it is calculated that 1 gram for 6 cubic feet of space is equal to 1 ounce for 170 cubic feet and 1 gram for $5\frac{3}{4}$ cubic feet is equal to 1 ounce for 163 cubic feet.

larvæ and pupæ of the white fly. To destroy the eggs, however, he found that a larger dose was necessary. The author fully concurs with Professor Gossard in his recommendation to defoliate completely all white fly infested nursery stock before shipping, and, as an extra precaution, to fumigate. The almost invariable experience of Florida nurserymen, however, shows that citrus trees should not be fumigated with roots bare. The fumigation is far less necessary than when the insects concerned are true scale insects and are attached to the stems. White flies have never been known to reach maturity except on the leaves, although eggs and crawling larvæ may occasionally be found on young growing shoots. It is safe to presume that there are no unhatched eggs of the white fly on anything other than leaves and young succulent growth of stems. When these are completely removed there need be no fear that the pest will be carried by means of the trees. The entire leaves, including the winged leaf petioles, must be removed, and when large shipments are concerned careful attention must be given to this. A greater danger than the trees themselves is found in the packing. This, as Professor Gossard points out, might be a possible source of danger if infested citrus leaves were allowed to get into the moss or other material used in packing. The danger is, of course, slight, but should nevertheless be borne in mind by shippers and buyers of nursery stock.

PRECAUTIONS.

As is customary in publications on entomology in which the use of potassium cyanid is recommended in combating insect pests, attention is directed to the extremely poisonous nature of this substance. There are on record no fatalities due to the use of potassium cyanid as an insecticide against orchard pests, but this is because the danger from careless use was well known and simple precautions were observed. In weighing the doses it is recommended that the hands be protected by leather gloves, and after starting the generation of the gas the operator should avoid breathing until he is outside in the open air. A slight choking sensation experienced when standing close to the tents during the fumigation acts as a danger signal, and one should not persist in remaining where the gas is dense enough to produce this result. The acid should always be handled with great care. In addition to precautions necessary for the safety of the operators, care should be taken to avoid the scattering of small particles of the cyanid where fowls or other animals might become poisoned. As this substance is readily soluble in water and is deliquescent, or capable of liquefying through the absorption of moisture from the air, small particles accidentally dropped soon disappear.

Other precautions which it seems desirable to emphasize at this time concern the avoidance of damage to the tents and trees. Tents should never be dragged over the ground where the residue of the jars has been poured out on the surface or where the material has boiled over during the generation of the gas. The safest rule is to avoid entirely the dragging of tents across sections of the grove which have been recently fumigated. The residue or contents of the jars after fumigating is very destructive to citrus trees if emptied against the base of the trees. When emptied 3 feet or more from the base of the trees there seems to be no danger whatever unless roots are exposed, but to avoid all risk it is recommended that the practice be adopted of burying the residue halfway between the rows, as described under the subject of methods of procedure. Tents should not be left during the day covering trees which are to be fumigated at night, for the inside temperature is quite likely to be raised to a point where the gas will cause excessive shedding of the foliage.

EXPENSE OF FUMIGATION.

FOR EQUIPMENT.

The cost of the equipment, aside from the fumigating tents, is of little importance. In procuring a set of tents one may either purchase the material and arrange for the construction to be done by a tentmaker according to directions, or the maker may provide the material and furnish the tents according to specifications at regular prices. It will be found advantageous to obtain quotations from several tentmakers before placing an order. To give an idea of the usual cost of fumigating tents in California, the following schedule of prices recently quoted by a leading maker of fumigating tents in that State is given:

TABLE XII.—*Schedule of prices for sheet and bell fumigating tents.*

Sheet tents, 8-ounce duck.		Bell tents, 6½-ounce drill.	
Diameter.	Price.	Dimensions.	Price.
Feet.		*Feet.*	
17	$6.12	6 by 7	$2.66
24	12.24	8 by 9	4.55
30	18.90	6 by 12	5.72
36	27.00	9½ by 11	6.76
41	34.20	10½ by 14	9.10
43	41.40	12 by 15	13.00
45	43.74		
48	47.70		
52	59.40		
55	65.70		
64	86.40		

The cost of the sheet tents would be considerably reduced by the use of one or two widths of 6½-ounce drill, sewed around the margin as a skirt, as described under the subject of construction of fumigating tents. The difference between the cost of tent materials in California and in eastern citrus-growing States, owing to the greater distance of the former from the factories, should result in a reduction of from 2 to 5 per cent in the cost of an outfit at any point in the Gulf States. In Florida the season for fumigating against the white fly extends over from seven to ten weeks. During this time a fumigating tent, used between thirty-five and fifty days on an average of eight hours per day with forty-five minute exposures, would be used to cover between 280 and 400 trees. A tent large enough to cover the largest trees should ordinarily not cost over $110. It has been stated that the tents used in the author's experiments in January and February, 1907, have not deteriorated appreciably. With proper care tents should last several seasons, whether untreated or mildew-proofed. If such a tent as referred to above should be used for only three seasons, and be used to cover only between 280 and 400 trees each season, the cost of the wear and tear of the tent would amount to only from 9 to 12 cents per tree. Even taking into consideration interest on the money invested, the cost per tree would not exceed 15 cents. This is fully twice the cost of a tent large enough to cover trees of average size.

In many cases it would not be advisable for an orange grower to invest several hundred dollars in fumigating tents for his exclusive use, although many with extensive groves would doubtless prefer to do this. When possible individual ownership of an outfit is desirable. In some citrus fruit growing countries where fumigation is practiced against scale insects several growers form a club and share the cost of the fumigating outfit, which is left at the disposal of each of the members in turn. Such a plan might be followed in many cases in Florida. It is especially to be recommended where several groves constitute a naturally isolated group, and cooperation has all the advantages of individual ownership of a single isolated grove. A few citrus growers with a crop worth on an average $25,000 would not be put to unreasonable expense in the joint ownership of an outfit costing $1,200 or $1,500. The rapid growth of the idea of orange growers' associations in Florida during the past few months leads to the hope that a means is at hand for providing for systematic campaigns against citrus pests. In some cases associations for this purpose have already been organized. Fumigation by the contract system, as it is now done to a large extent in California, may also come into use in Florida. The plan which can be most strongly recommended is for the work to be done by the various counties. Each county where the citrus-growing interests are of importance should maintain an outfit of tents large enough for the needs of the orange growers within its limits, and fumigation should be done at cost under the direction of the county horticultural commission.

FOR CHEMICALS.

The principal item of expense in connection with fumigation is the potassium cyanid. Fumigation was considered profitable in California when this was sold in quantities for 65 cents per pound. At present in lots of 100 pounds this can be procured for about 30 cents per pound, while in ton lots the cost is from 20 to 23 cents per pound in Florida. Sulphuric acid in iron drums containing about 1,500 pounds can be obtained for about $1\frac{1}{4}$ cents per pound. In carboys containing about 200 pounds the cost is about 2 cents per pound.

FOR LABOR.

In California, labor is usually paid for by the hour. The foreman in charge of the outfit is generally paid about 40 cents per hour and the remainder of the crew about 25 cents per hour. A crew of seven men, which might be used to advantage with the method of procedure herein recommended for use in fumigating for the white fly, would cost $15.20 for a night's work of eight hours if wages were paid at the above rates. These men could ordinarily handle from 10 to 15 tents of the largest sizes every forty-five minutes and fumigate 80 to 120 trees in eight or nine hours. If 80 trees were treated, the cost for labor would be about 19 cents per tree. If smaller tents were used and handled with changing poles, the same crew could treat 200 trees in eight hours at a cost for labor averaging about $7\frac{1}{2}$ cents per tree. If six men proved sufficient to do this work, the cost for labor would be about 1 cent less per tree. In California contractors charge from 4 to 12 cents per tree for covering trees which can be covered without the use of the braced uprights or derricks. These prices include from the contractor's standpoint: First, cost of labor; second, cost of wear and tear on tents; third, a reasonable profit. Contractor's prices stated above are exclusive of about 3 or $3\frac{1}{2}$ cents per pound usually allowed as payment for handling the cyanid, the chemicals being furnished by the owner of the grove.

In estimating the expense for labor in fumigating a grove there should be included, in addition to the labor in connection with coverering the trees and generating the gas, an allowance for repairing tents, hauling chemicals and water, and miscellaneous work. This ordinarily ranges from 1 to 4 cents per tree, according to size.

ECONOMY OF TREATMENT BY FUMIGATION.

LOSSES PREVENTED.

Losses from the white fly.—When once the white fly (figs. 8, 9) is reduced to an inconsiderable quantity in a grove, much benefit will result from careful inspections and fumigations of single trees, or groups of trees, from time to time wherever the insects are found to be multiplying. This will greatly delay the time when the multiplication of the insects shall have made a general treatment again necessary. This practice is followed in California in the control of various scales. In well-cared-for groves, or where the county horticultural commissioners require it, scales are kept in complete subjection by fumigation and the appearance of only a few live scales on a tree is considered a reason for fumigating it and perhaps, also, surrounding trees as well, although these may appear entirely free from the pest. The best results from fumigation are obtained when once the various pests are brought under control by continuing the practice as a preventive rather than as a remedy. In other words, when conditions for successful fumigation for the white fly are favorable or after they have been made so,[a] fumigation can be practiced with such success that all damage from the white fly will be obviated. When once the practice has been adopted a grower should not wait until the foliage is blackened by the insects before fumigating the second time. It would be far more economical to fumigate regularly once in two years, and prevent all blackening of the foliage, than to fumigate once and wait until the fly

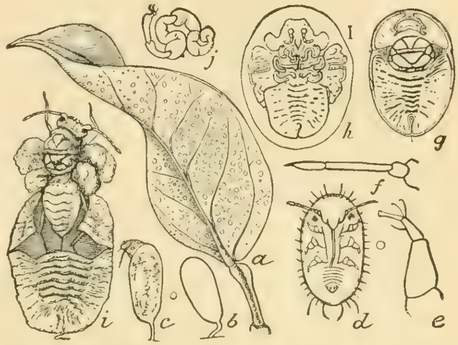


FIG. 8.—White fly (*Aleyrodes citri*): *a*, Orange leaf, showing infestation on under surface, natural size; *b*, egg; *c*, same, with young insect emerging; *d*, larval insect; *e*, foot of same; *f*, larval antenna; *g*, scale-like pupa; *h*, pupa about to disclose adult insect; *i*, insect escaping from pupal shell; *j*, leg of newly emerged insect, not yet straightened and hardened. All figures except *a* greatly enlarged (reengraved from Riley and Howard).

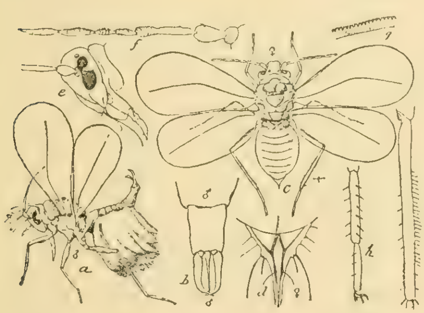


FIG. 9.—White fly (*Aleyrodes citri*): *a*, Winged male insect, with enlarged view of terminal segments at *b*; *c*, dorsal view of winged female, with enlargements of ovipositor, head, antenna, wing margin, and leg at *d*, *e*, *f*, *g*, *h*, *i*. (Reduced from Riley and Howard.)

[a] See discussion of this subject, pp. 9–14.

had increased sufficiently to cause blackening of the foliage and fruit before repeating the treatment.

The extent of the damage due to the white fly is difficult to estimate. After supplementing his personal observation with direct information and estimates on this point from more than 50 orange growers who have had experience with the pest, the author would consider 50 per cent a conservative estimate of the average annual loss in white-fly-infested groves.

The consensus of opinion of the orange growers referred to is to the effect that the reduction in the size of the crop alone amounts to 50 per cent or more, leaving out of consideration the loss through the checking of the growth of trees, the retardation of ripening, the expense of washing the fruit, and the impairment of its shipping quality and flavor. In many cases the damage from the fly renders citrus fruit growing unprofitable, although such losses are usually unnecessary if proper care be given to cultivation and fertilization. The beneficial effect of the fungous diseases of the white fly and the economy of fumigation where the diseases are prevalent will be discussed under another heading. The data at hand concerning the cost of fumigation indicate that in most cases the expense would be sustained by the increase in production if the losses of the white fly were only 10 per cent, instead of the 50 or more as generally estimated.

Losses from scale insects.—In calculating the benefits derived from fumigation, the effect of the treatment on other citrus pests is an important consideration. Fortunately the high average of humidity in the citrus-growing sections of the Gulf States results in the partial control of scale-insect pests which would otherwise make direct remedial measures necessary for profitable crops. The thoroughness of this natural control varies greatly in different groves according to local conditions. Fruit infested with the purple or the long scale is far less valuable, as a rule, than is clean fruit. If such fruit is cleaned before packing, the cost is usually from 10 to 15 cents per box. In the markets scaly fruit in rare instances brings as much as fruit free from scale, but ordinarily it brings from 25 to 75 cents less per box, even after being cleaned by hand. If not cleaned it may fail to find a market at any price. When handled by orange buyers and sold upon the tree, even a small percentage of scaly fruit frequently results in a considerable loss in selling value of the entire crop.

Direct information has been obtained from many orange growers and shippers concerning the effect of scales upon the value of fruit. The damage reported ranges from none at all to 26 per cent of the total value of the crop. Ordinarily from 5 to 15 per cent of the crops of oranges and grapefruit are sold as of an inferior grade owing to infestation by the long and purple scales. One grower in Lee County reported that last season (fruit shipped in December, 1906) he suffered a loss of $1,500 on a crop of 1,000 boxes of oranges and 2,000 boxes of grapefruit. All of the grapefruit and 300 boxes of the oranges were scraped by hand to remove the scale. This operation cost between $275 and $300. The loss to the selling value of the oranges was about $225 and of the grapefruit about $1,000. Many instances have come to the writer's attention of losses from scale amounting to 5 per cent of the total value of the crop. In addition to direct losses of the kind noted above, frequently more serious losses are suffered as a result of the complete destruction of branches and weakening of the vitality of the trees by the heavy incrustations of the scales upon the main branches or trunks. The total damage from scales in Florida is usually too small to make direct remedial measures profitable, but when this damage can be to a large extent obviated at the same time with that of the white fly, the matter demands careful consideration. It is the writer's conviction that in the cases of the majority of groves the destruction of the purple, long, Florida red, and other scale insects would represent an increase in profit which would by itself offset the cost of fumigation, leaving as clear gain the benefits derived from reducing the numbers of the white fly to a negligible quantity.

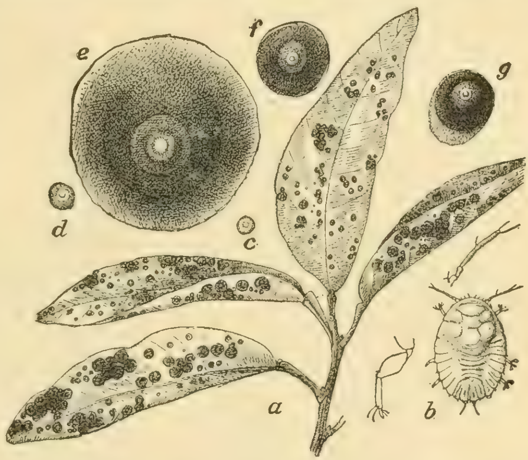


FIG. 10.—Florida red scale (*Chrysomphalus ficus*): *a*, Leaves covered with the male and female scales, natural size; *b*, newly hatched insect with enlargements of antenna and leg; *c*, *d*, *e*, *f*, different stages in the development of the female insect, drawn to the same scale; *g*, adult male scale, similarly enlarged. (After Marlatt.)

The Florida red scale (*Chrysomphalus ficus* Ashm.) (fig. 10) is destroyed with a thoroughness near to absolute extermination by the same dosage which is required for the white fly. This has been conclusively proved by the experimental work conducted by the writer and Mr. W. W. Yothers in January of the present year. Not infrequently in Florida the scale insect referred to causes sufficient injury to make fumigation a very profitable procedure against this insect alone, leaving out of consideration the effect upon the other pests present.

The purple scale (*Lepidosaphes beckii* Newm.) (fig. 11) sometimes called the "brown," "oyster-shell," or "hard" scale, is of greater economic importance than the Florida red scale on account of its more wide-spread distribution. The results in controlling this pest accomplished incidentally to work against the white fly are most encouraging. In the same grove where the effect of fumigation on the Florida red scale was observed, the purple scale has been so abundant for years that the owners' fruit-shipping records show annual losses from this source amounting to between 15 and 20 cents per tree. Live scales in all stages, particularly the egg and adult, were very abundant before fumigating, but up to the 1st of June careful examinations of thousands of leaves, twigs, and green fruits by Mr. Yothers and the writer have not led to the finding of a single living specimen of this species in the section of the grove which was the most heavily infested. At this season of the year there is usually no difficulty in finding more or less abundant specimens of the spring brood of this insect even where it was so scarce the previous season as to occasion no appreciable damage to the crop.

COST OF FUMIGATION COMPARED WITH SPRAYING.

In Florida the average cost of spraying is between 2½ and 3 cents per gallon of spray applied. When spraying is done with such effi-

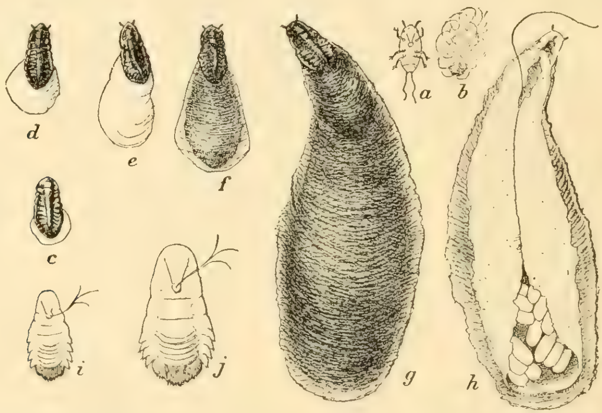


FIG. 11.—Purple scale (*Lepidosaphes beckii*), showing different stages of female: *a*, Newly hatched larva; *b*, same with first waxy secretion; *c* to *f*, different stages of growth; *g*, mature scale; *h*, same inverted, showing eggs; *i* and *j*, half-grown and full-grown female insects removed from scale. All much enlarged (after Marlatt).

ciency that blackening of the foliage and fruit by the sooty mold is prevented, at least three applications per year, and usually four or more, are necessary. The mechanical difficulties of spraying with as much effectiveness as this are so great as to make the results with ordinary practices far inferior to those from fumigating. In fact the results with sprays have with few exceptions been unsatisfactory in controlling the white fly or preventing the blackening of the fruit and foliage. In many cases this is largely a result of the character of the labor which it is necessary to employ for such work. For the purposes of comparing spraying with fumigating in regard to cost, it may be considered that three applications of sprays per year will control the white fly in a satisfactory manner, although in actual practice this is rarely accomplished unless drought or fungous diseases offer material aid

The tented tree shown in Plate VI, figure 2, measured 42 feet over the top from ground to ground and 59 feet in circumference. According to the table given in the appendix a tree of this size should be given 26 ounces of potassium cyanid. In covering a tree of this size ordinary changing poles could be used instead of the upright shown in the illustration. The entire cost of fumigating the tree for the white fly is estimated at 50 cents. This includes 36 cents cost of potassium cyanid, 3 cents cost of acid, 6 cents cost of labor, and 5 cents cost of wear and tear on the tent. The tree shown at the left of the tent in Plate VI, figure 2, measured 44 feet over the top and 53 feet in circumference. According to the tables the tree requires 25½ ounces of potassium cyanid, the cost of fumigating therefore being practically the same as for the first tree mentioned. Each of these trees if sprayed would require six or seven gallons of liquid at each application. Three applications in a year at the usual cost would be from 45 to 63 cents as compared with 50 cents for fumigating. The tree shown in Plate I measured, when tented, 33 feet over the top and 38 feet in circumference. A tree of this size requires 12 ounces of potassium cyanid for effective fumigation. The total cost of one fumigation would be about 27 cents, including 16 cents as cost of potassium cyanid, 6 cents as cost for labor, 1 cent as cost for acid, and 4 cents for wear and tear on the fumigating tent. A tree of this size would require at least 3 gallons of spray at each application, and during the year the cost for three applications would be from 22 to 27 cents.

These data on the comparative cost of the two methods of control show that the advantage of fumigation over spraying for the first year is a matter of greater efficiency, except when more than three applications of spray are made, when fumigation is also less expensive. Fumigation, however, in an isolated grove or under favorable conditions as to location, when properly conducted would not require repetition for two or more years. The best of spraying could not, unless aided by abnormal climatic conditions, so reduce the white fly that the number of applications could be lessened the second year without interfering with the degree of success attainable by the practice. In two years the cost of spraying the trees above referred to would double the cost of one fumigation. In a series of five or more years spraying would doubtless cost fully three times as much as would control by fumigation, the labor involved would be far greater, and the results far less satisfactory.

FUMIGATION VERSUS NATURAL CONTROL.

The present investigation of the white fly by the writer and his associates covers all phases of the subject. Due consideration is given to all possible sources which give basis for the hope of effecting economical control. The exposed condition of the pest under consideration, its vulnerability to attack by natural enemies, the high degree of humidity in the citrus-growing regions of the Gulf States which favors the effectiveness of fungous and bacterial diseases, all give basis for the hope that complete control by natural enemies will be the eventual conclusion of the white-fly problem. A thoroughly scientific and practical investigation, however, can not lead to lasting benefits if the conclusions represent merely desired results and are unsupported by sufficient evidence and experience. While a great deal has been learned concerning the fungous diseases of the white fly, the present investigations of this Bureau have not thus far shown that any method can be relied upon to materially assist nature in controlling the pest to the point of preventing all or nearly all of its injury. The dissemination of these diseases is readily accomplished under certain favorable conditions, but how far artificial dissemination, at its best, with our present methods goes toward the successful control of the white fly is still problematical.

Manatee County is the only large orange-growing district where the fungous diseases have proved of much assistance. Data obtained from many orange growers and personal observation by the writer and other entomologists connected with the Bureau of Entomology indicate that the fungi, without artifical aid, reduce the injury from the white fly about one-third. Undoubtedly without the aid of these fungous friends the damage in Manatee County would average more than 50 per cent. With this as a minimum estimate, the average damage in Manatee County, allowing a benefit of one-third from the fungi, amounts to 34 per cent. One year in three, it is the experience of the growers in this county, the fungi have so thoroughly cleaned up the pest that the fruit is clean and requires no washing. The following year the insects are in the ascendency and the fruit and foliage become blackened with sooty mold to as great an extent as can be observed anywhere in the State. This is due to the fact that the fungi have diminished the white flies the previous year to a point where they cease to flourish. Late in the second year, however, with the fly abundant, the fungous enemies develop rapidly. The third year the effect of the blackening of the foliage is apparent in a greatly reduced crop, while during this year the fly is again reduced to a negligible quantity, permitting a good crop of fruit to set and remain clean from sooty mold during the following season. The above is the usual course followed in individual groves. Considering the county as a whole in 1906, fully three-fourths of the groves were so free from sooty mold as to require no washing of the fruit. It was generally considered that this condition had never before been equaled since the white fly first obtained a foothold in this county. In one case, however, it was claimed by one of the leading orange growers that an isolated grove had become practically clean through some unknown agency, the prevailing fungous diseases not being present in sufficient abundance to accomplish any noticeable result. Nevertheless, the fungous enemies referred to were undoubtedly of prime importance in producing the high degree of freedom from white-fly damage attained in 1906. Other conditions may have had minor influence. As a natural consequence of the lack of abundant food for the fungous parasites in 1906, the situation in 1907 showed a complete reversal, with more than three-fourths of the groves thoroughly blackened by sooty mold. It is not uncommon to find that individual groves vary considerably from the average condition of the groves in the county as a whole.

In the close vicinity of Fort Myers, in Lee County, the fungi have reduced the numbers of the white fly to a greater extent than observed at any other place. The result of this is to cause a considerable variation from the usual succession of predominance of host and parasite, but in the course of a ten-year period the benefits from the fungous diseases under natural conditions will evidently be little if any greater than in Manatee County. In the town of Fort Myers the conditions are not comparable with those in large commercial groves. In one such grove, however, located on the south side of the Caloosahatchie River, nearly opposite Fort Myers, the fungous diseases have proved more than ordinarily beneficial during the past two years. There is strong evidence even here that the white fly will regain its usual abundance in the course of the present season unless artificial methods of control are resorted to or experiments result in the discovery of a more satisfactory method than is now known of artificially encouraging the growth and spread of the fungous enemies.

The writer's observations lead to the conclusion that in 99 per cent of the groves in those localities where the fungous diseases are most effective, for every dollar expended for well-conducted fumigation the profits from the groves will be increased not less than $4, or at the rate of 250 per cent on the investment. If the expense of fumigation were doubled the adoption of this practice would still be profitable, at least until such time as the natural enemies at hand can be made more successful or new ones discovered to accomplish effective control.

The spores and mycelium of the fungi are not affected by fumigation, as far as has been determined thus far. In experiments in the artificial dissemination of the brown and red fungous parasites the results obtained were as satisfactory when the material was collected from fumigated trees as when collected from those not fumigated. Ordinarily this point is of little importance, since successful fumigation would always result in practically absolutely checking the further multiplication of the parasites through the destruction of the host insects. The further multiplication of the fungous parasites following fumigation is therefore an indication of ineffectiveness of the treatment or of the increase in the numbers of the pest through migration from untreated groves.

APPENDIX.

TABLE OF DOSAGE FOR THE CITRUS WHITE FLY.

The table of dosage herein given is based upon the author's experiments conducted in January and February, 1907. The mathematical calculations are tabulated and explained in the body of this bulletin. The most important object of fumigation experiments against the white fly has been the development of methods for the practical utilization of the fumigation process in Florida and the gaining of a knowledge concerning the dosage requirements. The former subject has already been disposed of through the methods herein described. The investigations concerning the latter subject have resulted in placing fumigation for the white fly on a basis whereby the process may be used against this insect with greater economy, thoroughness, and certainty of results than at present it can be used against any other species. Incidentally it should be remarked that the dosage requirements for the white fly are greater than for the Florida red scale and perhaps greater also than for the purple scale. It is beyond the scope of these investigations to determine the possibility of reducing the dosage below the white fly standard without interfering with its efficiency against these other pests. It is sufficient to know in most cases that the white fly dosage is equal to the actual requirements for the pests of secondary importance. The dosage table here presented does not necessarily represent the exact amounts for greatest utility in the case of the different sizes of trees. The extensive tests of the dosage table during the past winter, when, as has been stated, nearly 4,000 trees were fumigated under the direction of the agents of the Bureau of Entomology, show the doses recommended to be very close to the necessary amounts with tents of equal tightness with those used in the original experiments. The dosage should never be decreased when effective work against the white fly is desired, but under certain conditions it may be increased from 10 to 25 per cent with advantage.

If there is a slight breeze of sufficient strength to make the advisability of fumigating questionable, an increase in dosage of 10 per cent or more may allow the work to proceed without interfering with the efficiency; but with ordinary tents of 8-ounce duck such increases do not offset the effects of strong or gusty breezes, which sway the sides of the tent. If the only available tents are of inferior quality and fall short of being as nearly gas-tight as the best of material, increases in dosage may be advisable. When it is desired to fumigate with a thoroughness approaching extermination, an increase may be made of from 10 to 25 per cent. Such a course is frequently advisable to check the further spread of the fly in newly infested localities or in newly infested groves. In the fumigation of very small trees, 20 feet over or less, there seem to be certain factors sometimes interfering with efficiency which have not so far been thoroughly investigated. It is possible that in the using of crocks of 2 or 3 gallons capacity for doses less than 5 ounces the mixture of acid and water fails to generate sufficient heat to cause quick chemical action, the heat absorbed by the jar being the disturbing factor. This may be partly obviated by using powder or very small lumps of potassium cyanid when the dose is 5 ounces or less, but it seems advisable also to increase the amount by one-half or three-fourths above the recommended dose. If the size of the crock and consequent undue loss of heat is the principal disturbing factor, future experience may show that it is desirable to have on hand for use in fumigating very small trees a supply of half-gallon crocks or 1-quart stone chinaware pitchers.

In the table the amount in each case represents the next half ounce above the dosage which the detailed estimate calls for, whenever this dosage was more than one-tenth ounce above the even ounce or half ounce. For example, when the detailed calculation calls for 19.2 ounces the number in the working table is 19½ ounces, and when for 19.7 ounces the number is 20 ounces. In using the table in the field, when the reading on the graduated tent shows the approximate distance over the top to be an odd number of feet, the next even number above should be selected. In the same way, when the exact circumference is not shown at the top of the table, the next highest number should be selected.

To illustrate the method of using the table of dosage, the following examples show the measurements and dosage called for in the case of five trees of various sizes:

Measurements of, and dosage for each of five trees of various sizes.

Distance over tented tree.	Circumference of tented tree.	Amount of potassium cyanid called for.
Feet.	*Feet.*	*Ounces.*
28	45	10
48	60	34
54	68	47
60	74	61
72	80	89

At all times it should be borne in mind that it is advisable to use one-half or even 1 ounce more than called for by the table rather than the smaller amount.

Proper dosage (quantity, in ounces, of potassium cyanid) for fumigating, based upon the distance over and the circumference, in feet, of the tented tree.

Distance over.		Circumference.																								
		10	15	20	25	30	35	40	45	50	52½	55	57½	60	62½	65	67½	70	72½	75	77½	80	82½	85	87½	90
1	10	1	1	1																						
	12	2	2	2																						
	14	2½	2½	2½	2½																					
	16	3	3	3	3	3																				
	18		4	4	4	4	4																			
2	20		4½	4½	4½	4½	4½																			
	22			4½	5	5½	5½	6																		
	24			5½	6	6	6½	7	7½																	
	26				7	7	7½	8	8½																	
	28				8	8½	8½	9	10	10½																
3	30					9½	10	10½	11	11½																
	32					10½	11	11½	12½	14	15															
	34					12	12	13	14	15½	16½	18														
	36						13½	14½	15½	17	17½	18½	19½													
	38						15	16	17	19	19½	20½	21½	22½												
4	40							17½	18½	20½	21½	22½	23½	24½	25½											
	42							18½	20½	22½	23½	24½	25½	26½	27½	28½										
	44								22	24	25	26½	27½	28½	29½	31	32	33½								
	46									26	27	28½	29½	31	32	33½	34½	36	37½	39						
	48									27½	29	30½	31	33½	34½	36	37½	38½	40	41	42½					
5	50										31	32½	34	35½	37½	39	40½	42	43½	45	46½	48				
	52											34½	36	38	40	41½	43	44½	46½	48	50	51½	53½			
	54											37	38½	40½	42	44	46	48	50	51½	53	54½	56	57½		
	56												41	43	45	46½	49	51	53	54½	57	59	61	63	65	
	58												43	45	47	49	51½	54	56	58	60½	62½	65	67½	70	
6	60													48	50	52	54½	56½	59	61	63½	65½	68	70	72½	75
	62													50	52½	55	57½	60	62	64½	67	69½	72	74½	77½	
	64													53½	55½	58	60½	63	65½	68	70½	73½	76½	79½	82½	85
	66													55½	58	61	64	67	69	71	74½	78	80½	83	85½	88
	68													58½	61	64	66½	69½	72	75	78	81½	84½	87½	90½	93½
7	70													61½	64	66½	69½	72½	75½	78½	82	85	88	91	94	97
	72													64	66½	69	72	75½	79	82½	86	89	92	95	98	101½
	74													67½	70	71½	75	78½	82	86	89½	93	96	99½	103	106
	76													70	73	75½	79	82	86	89½	94	97	100	103½	108	111½

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U. S. DEPARTMENT OF AGRICULTURE,

BUREAU OF ENTOMOLOGY—BULLETIN NO. 77.

L. O. HOWARD, Entomologist and Chief of Bureau.

HIBERNATION OF THE MEXICAN COTTON BOLL WEEVIL.

BY

W. E. HINDS AND W. W. YOTHERS,

UNDER THE DIRECTION OF

W. D. HUNTER.

ISSUED OCTOBER 18, 1909.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1909.

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LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Bureau of Entomology,
Washington, D. C., October 6, 1908.

Sir: I have the honor to transmit herewith for publication as Bulletin No. 77, of the Bureau of Entomology, a manuscript prepared by Dr. W. E. Hinds and Mr. W. W. Yothers under the direction of Mr. W. D. Hunter. This manuscript deals with the hibernation of the Mexican cotton boll weevil. The winter season is a critical period in the life history of this very destructive pest. An exact knowledge of its hibernation throws much light on practical control. For this reason careful experimental studies have been carried on for several years. On account of their importance the results are presented somewhat in detail. The illustrations will add greatly to the clearness and force of the text.

Respectfully,

L. O. Howard,
Entomologist and Chief of Bureau.

Hon. James Wilson,
Secretary of Agriculture.

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PREFACE.

Natural conditions annually reduce enormously the numbers of the cotton boll weevil. Although no two seasons are exactly alike, never more than a small percentage of the weevils in the fields in the fall is permitted to survive until spring. In fact, winter is the most critical season in the whole life history of the weevil. Any steps in control of the weevil during the winter are therefore much more important than those which can be taken at any other season of the year. To destroy ten weevils in the winter is much better than to destroy many thousands in the summer. The cotton boll weevil is now causing a damage in the United States each year of at least $25,000,000. The indications are that this amount will continue to be lost for some time at least on account of the difficulties in control which will be encountered in the Mississippi Valley. For these reasons the Bureau of Entomology has conducted careful investigations of the hibernation of the weevil and presents the somewhat detailed results in this bulletin.

Until this time the hibernation of the boll weevil has been less understood than any other phase of its life history. This was due to the great difficulty in obtaining the necessary data and the fact that the phenomena of hibernation are not necessarily identical in different seasons. In fact, it will be seen from the following pages that there have been very important dissimilarities between the years when special observations have been under way. The necessary repeated work in large cages in different localities has now been carried on and extensive field observations have been made in various representative parts of the infested area as to the natural situations in which the hibernating weevils occur. As a result, the present bulletin will make the life history of the boll weevil during the winter season at least as well known as any other portion of its biology.

In the work leading to this bulletin practical considerations have always received primary attention. However, it has repeatedly been shown that careful detailed investigations of injurious insects may result in important suggestions for control that are not foreseen at the beginning of the work. Therefore the topic of the hibernation of the boll weevil has been investigated from every possible standpoint. Its importance, as a critical period in the life history of a most injurious pest, has abundantly warranted this work.

Foremost among the points of immediate practical application shown in this bulletin is the enormous importance of the fall destruction of the plants. This has been one of the recommendations of the Bureau of Entomology for some years. Its importance will increase rather than diminish in the regions now invaded by the insect. The cage experiments at Dallas, Calvert, and Victoria, Tex., in the winter of 1906–7 have given most important and accurate data showing exactly what may be accomplished by the fall destruction of the plants at various dates. This bulletin, moreover, shows the most favorable and least favorable conditions in the hibernation of the weevil. This information can be put to practical use by every farmer in the infested area. It shows exactly where the most effective work can be done. A not unimportant feature is the showing of the absolute impracticability of late planting to obviate damage by the boll weevil by reason of the remarkable longevity of hibernated individuals without any green food whatever.

The information included in this bulletin has been accumulated through the investigations and observations of the numerous agents connected with the work during the seasons of 1902–1907. Some of the facts have been briefly stated in previous publications, particularly Bulletins 45 and 51. The manuscript for the present publication was prepared during the summer and fall of 1907, and since that time some of the conclusions drawn from this study have been published in connection with other bulletins and circulars relating to the weevil and its control. But in no other instance have all of the facts been considered or their complex, intimate, and important co-relationships studied as in this work.

On account of the large amount of work that has been done and the practical importance of many of the conclusions drawn it has been considered that full indication should be made in the bulletin of the methods by which the conclusions and recommendations are reached. Therefore special pains have been taken to give all essential data and to represent by charts matter that can thus be graphically expressed.

It will be noted that the various experiments dealt with in this bulletin are taken up according to the years in which the work was carried on. The result is that some special topics, such as time of entrance into hibernation, will be found discussed in several places. It has been found entirely impracticable to follow a strictly topical system and discuss each point connected with hibernation with reference to the work of the various years. This impracticability is due principally to the great natural variations in the seasons. Nevertheless the first part of the bulletin discusses the general feature of hibernation and the summary at the end has been written in such a way as to bring the principal conclusions on the various topics into condensed form.

The question of credit to the various investigators who have contributed to this bulletin is rather complicated. Mr. E. A. Schwarz studied carefully the hibernation of the weevil at Victoria, Tex., in the winter of 1901–2 and his observations have been utilized. Later Mr. Wilmon Newell, secretary of the State Crop Pest Commission of Louisiana, assisted by Mr. J. B. Garrett, planned and executed a series of experiments in the hibernation of the weevil which was much more extensive than any similar work that had been done up to that time in this country. This work was done in cooperation with the Bureau of Entomology, and the results, through the liberality of Mr. Newell, have been largely incorporated into this bulletin. Mr. J. D. Mitchell contributed important facts from observations during several seasons, especially with reference to actual winter field conditions. Many of the details in the plans for the extensive work of 1906–7 were worked out by Dr. W. E. Hinds, who also superintended the extensive tedious work necessary during the following spring. In all this work Doctor Hinds was assisted by Mr. W. W. Yothers, by Mr. A. C. Morgan, who had charge of the work with the large cage near Victoria, and by Mr. C. R. Jones, who was located at Calvert. Mr. Yothers collaborated with Doctor Hinds in the arrangement and correlation of the data obtained at the places mentioned and in placing in manuscript form the records of many of the experiments of previous years. For two winters Mr. Yothers carried on special observations, largely of his own planning, as to actual field conditions. In this work he collected large quantities of bolls and various forms of trash in and about cotton fields, and from careful examinations of this material in the laboratory he was able to determine many very important facts in regard to the several classes of rubbish, or winter shelter, which are most likely to protect weevils and to insure their successful survival through the winter season.

W. D. Hunter,
In Charge of Southern Field Crop Insect Investigations.

HIBERNATION OF THE MEXICAN COTTON BOLL WEEVIL.

ENTRANCE INTO HIBERNATION.

In the study of hibernation of the Mexican cotton boll weevil (*Anthonomus grandis* Boh.) we shall first consider the factors affecting the abundance of weevils which may enter hibernation, the dependence of the number of weevils present upon preceding conditions of food supply, the climatic conditions accompanying or producing the beginning of hibernation, and other biological facts which may be of interest or value in connection with this division of the subject.

SUPPLY OF WEEVILS TO ENTER HIBERNATION.

The common name "cotton boll weevil," which is uniformly applied to this insect, may be in part at least responsible for a misleading impression in regard to the most common point of attack and place of development of this weevil. The common name was first applied because of the fact that in the first recorded case of this insect attacking cotton the specimens were found in bolls. It is a fact, however, that by far the greater number of weevils to be found in any field at any season of the year have really developed within the buds or squares rather than within the bolls. In the first place, it is perfectly evident that during the entire growing season of the plant, in the infested area, probably not much more than 10 per cent of the squares which form ultimately produce bolls. For this reason the weevils find opportunities for reproduction many times greater in squares than in bolls. In the second place, a careful study of the habits of the weevils shows that they prefer squares both for feeding and for reproduction. In the third place, the average period required for development in squares is only one-half to one-third as great as it is in bolls which become more than one-half grown. These three considerations insure a far more rapid and abundant multiplication of individuals through the medium of squares than through bolls. Wherever weevils have been present in average abundance at the beginning of the season, unless they have been unusually checked by climatic conditions unfavorable to their development, a condition of total infestation of squares is usually reached between August 1 and 20. By this time practically all of the crop which can be expected will have been set and many of the oldest bolls will be found maturing. If a moderate crop of bolls is being matured the formation of squares usually ceases, almost if not entirely, for a period of several weeks. Whereas in the early part of the season female weevils could find abundant opportunities for depositing their eggs in previously uninfested squares, after the time of total infestation is reached such opportunities practically cease to exist. The available supply of squares and bolls becomes too small to support the large number of weevils which may be present, and conditions become decidedly unfavorable for their further multiplication. It is at this season of the year, usually from August 15 to September 20, that the largest general dispersion movements of the weevils take place. It is at this season also, during recent years, that the cotton leaf-worm has become sufficiently abundant to secure a partial or complete defoliation of the plants. While the occurrence of the leaf-worms is by no means regular, the effect of their work is to still further limit the available food supply of the boll weevil and to force them into a more general dispersion from the defoliated plants. On account of the reduced supply of squares, the increased period of development in bolls, and the extensive dispersion movements of the weevil at this season of the year, it usually happens that the actual number of individuals in a field becomes greatly reduced.

Following the maturity of a considerable portion of the crop of bolls, and usually in connection with the occurrence of a heavy rainfall, a renewed growth of the plant commonly produces an abundance of squares. It is this late top growth of the plant, which serves no good purpose so far as further production of cotton is concerned, that is primarily responsible in most fields for the needlessly large number of weevils produced between the time of maturity of the crop and the usual time of destruction of the plants by frost. A large proportion of the weevils which become adults before September 1 may be expected to die, either as cold weather comes on or during the early part of the winter season. The later-developed weevils, however, have not exhausted their vitality and are much more likely to survive the full hibernation period. The importance, therefore, of preventing or of reducing the formation of squares following the period of maturity of the bolls can be easily appreciated.

To sum up briefly the principal points in the development of weevils which may enter hibernation, we may say that from the beginning of the formation of squares until the plants are destroyed by frost the development of the boll weevil is a continuous process. During the usual fruiting period of the plant it is possible that as many as eight generations of the weevil may be produced, especially in southern Texas. It is also possible that during this period individuals may exist which represent an advance of only one generation. During the entire season the average period required for development, in squares, from the deposition of the egg to the emergence of the adult weevil is from 18 to 20 days. In bolls the developmental period may exceed 60 days. The average period during which each female may deposit eggs is between 50 and 60 days. The average number of eggs which each female may be expected to deposit is not far from 100. The average period required for each generation is between 40 and 45 days. In southern Texas, therefore, five full generations of the weevil may usually be expected, and owing to the somewhat shorter season and lower temperatures occurring in northern Texas four generations is probably the true average in that section of the State. There is no particular hibernation brood, but representatives of all generations may survive and enter hibernation. From these considerations it will be readily understood that during the latter part of the season the multiplication is primarily dependent upon the food supply, and that the common practice of allowing stalks to stand after the crop becomes matured is primarily responsible for a large proportion of the weevils which may enter hibernation.

It is but repeating statements which have been frequently made in former publications of this investigation to say that the vain hope of securing some top crop of cotton, in case there should be a late fall, is probably the principal reason which has been urged for allowing this growth of the plant. So far as we know there is no record of a top crop ever having been secured in a field which had become thoroughly infested with boll weevils earlier in the season. While it is true that in uninfested regions some top crop has occasionally been formed and may occasionally be secured in the future, it is not putting the facts too strongly to say that within the weevil-infested area this has never occurred and should never be expected.

STAGES ENTERING HIBERNATION.

The reproductive activity of the weevil continues steadily until the plants are destroyed by frost. It gradually decreases coincidently with the gradual decrease in heat. All stages from the egg to the adult may be found in both squares and bolls, even after frosts have occurred. The immature stages in squares are not immediately killed unless the freeze is exceptionally severe, but probably very few of these survive to reach maturity and to emerge during the following spring. Only those which are nearly adult at the time frost occurs may be expected to emerge. These might emerge upon warm days following the colder weather, but in the absence of a fresh food supply would soon die. In the fall of 1903 Prof. E. D. Sanderson records, from an examination of 700 squares at the middle of November, finding 79 eggs, or that 11 per cent of the squares contained eggs. From an examination of 1,600 squares he states that 366 larvæ were found, showing that about 23 per cent of the squares contained larvæ at the time of entrance into hibernation. Some stages may survive in squares for a short time after the freeze, but there are few records of weevils entering hibernation at immature stages in squares and surviving to emerge therefrom in the spring. These stages are therefore unimportant from an economic point of view.

With immature stages entering hibernation in bolls (Pl. II, fig. 3) the case is quite different from that in squares. Extensive examinations have been made at various times in widely separated localities to determine the possibility of these stages maturing in the bolls during the winter and emerging in the spring. About the middle of November, in the winter of 1903–4, it was sufficiently cold at Victoria to destroy cotton plants. By the last week in December two hard frosts and one freeze had occurred, but at that time living larvæ, pupæ, and adults could be very commonly found in unopened bolls. Two weeks later, upon making another examination, Mr. J. D. Mitchell found a smaller proportion of larvæ with more pupæ and adults. Examinations were also made on January 17 and 31 and February 4 and 17, 1904. In the course of these examinations 23 larvæ, 30 pupæ, and 144 adults were found, and most of them were living. At Terrell, Tex., on December 15, 1904, in examinations of 200 bolls Mr. C. R. Jones found 101 larvæ, 16 pupæ, and 4 adults, all of which were alive. Fifteen days later, in examining 100 dry bolls, he found 20 larvæ, 16 pupæ, and 8 adults. Sixty per cent of the larvæ, 87.5 per cent of the pupæ, and 62.5 per cent of the adults were alive on December 30. On January 7, 1905, in an examination of 300 dried bolls 29 larvæ, 19 pupæ, and 13 adults were found, while the percentage of living, in each stage, had fallen to 17.2 for larvæ, 15.8 for pupæ, and 7.7 for adults. At Wharton, Tex., after the middle of November, 1905, an examination of 52 bolls disclosed 30 larvæ and 2 pupæ, all of which were alive.

These records might easily be multiplied, but it is unnecessary to do so to prove that very large numbers of weevils enter upon the period of hibernation as immature stages and that during many seasons, especially in the southern part of the State, a large percentage of these complete their development, and that many weevils may survive until time for their emergence in the spring. This point is emphasized especially because of its significance in regard to the most advisable method for destroying the stalks together with the infested unopened bolls which may remain upon them late in the season. Upon page 26 will be found records showing the results of extensive examinations of bolls during the winter and early spring, which add much emphasis to this point.

TIME OF ENTERING HIBERNATION.

Before discussing the question of the time at which weevils usually "enter hibernation" it seems desirable to explain the sense in which that term is used. The action of the weevils in securing shelter from approaching cold is not intelligent. It is probably true that they have no such sense of sight as we commonly understand from the use of that word and that their selection of shelter is not at all guided by that sense. We mean by this that a weevil on a cotton plant can not see at any distance shelter which might be attractive to it and thereupon fly from the plant to the shelter. It is true that cold nights with a temperature between 40° and 50° F. succeeded by warm still days, such as occur commonly in the fall, do seem to stimulate the weevils to an unusual activity both in flight and in crawling. It may be true that they have an instinctive knowledge of the approach of temperature conditions from which they must secure shelter, but it is also true that many weevils remain active upon plants for some time after the plants have been destroyed by frost and frequently until several weeks after other individuals have entered hibernation. In speaking of entering hibernation, therefore, we mean the entrance of the weevils upon a period of comparative if not complete inactivity. Their action in securing shelter is gradual and governed primarily by the degree of protection from the cold which they may receive. If early in the season a weevil accidentally finds shelter which gives it exceptional protection from the cold it will likewise be exceptionally protected from heat, and therefore less likely than are other less fortunate individuals to resume its activity upon warm days. If at first the shelter which weevils find is but slight, they will be easily influenced by succeeding warmth, and in another period of activity will be likely to find better protection. Their flight upon warm days undoubtedly leaves large numbers of them outside of the cotton fields, where they are as likely to find favorable shelter as within the fields themselves.

From this explanation it will be understood that it is rarely possible to indicate by a single date the time when weevils enter hibernation. It may be better expressed as a period within the limits of which a large majority, though possibly not all, weevils may seek shelter. Naturally this time varies according to the seasonal temperature conditions, so that in one locality it may occur several weeks earlier in one season than in another. It is also evident that differences in temperature conditions due to latitude or altitude will cause a similar variation in the time when weevils enter hibernation. In the following paragraph are given the approximate dates which have been determined for this event at various localities since 1902.

At Victoria, Tex., large numbers of weevils were still active in the fields about the middle of December, 1902, at which time direct observations were discontinued. It is probable, however, that weevils were gradually seeking winter quarters at any time after the first of that month. Prof. E. D. Sanderson states that at College Station, Tex., in 1903 weevils did not enter hibernation until after a freeze which occurred on November 18. After this date they soon disappeared. In 1903, at Victoria, hibernation began between November 15 and 30. At several points between College Station and Terrell, Tex., in 1904, hibernation began about November 10 and was not complete until early in December. During this same year at Victoria it occurred during the period from November 11 to about December 8. The following year at Victoria it did not occur until after December 15, while in 1906 at the same place weevils entered hibernation between November 9 and 20. At Dallas, Tex., in 1905, few weevils entered hibernation before the end of November, when heavy frosts occurred, but they disappeared in the fields during the first few days of December. At Dallas in 1906 weevils entered hibernation between November 15 and December 1.

These conclusions as to the approximate periods when weevils entered hibernation are based upon field observations which showed the gradual disappearance of the weevils from the plants. The conclusions from field observations are supported, also, by those from cage experiments.

PROPORTION OF EACH SEX AMONG WEEVILS IN FALL.

Determinations of sex proportion among weevils in midsummer have shown that during that period the sexes exist in approximately equal numbers. As the development becomes retarded by approaching cold weather there seems to be a tendency toward the production of more males than females. The generally longer life of males may also account in part for the increased proportion of that sex, which is shown in the following table:

TABLE I.—*Proportion of male and female weevils at time of entering hibernation.*

Year.	Male.		Female.	
	Number.	Per cent.	Number.	Per cent.
1904	557	63.7	317	36.3
1905	63	57.7	127	42.3
1906	173		78	
1906	173		127	
1906	19	57.6	14	42.4
1904	31	62.0	19	38.0
1906	29	52.7	26	47.3
	1,045	60.0	708	40.0

From this record it appears that at the time of entering hibernation male weevils largely predominate, being in the proportion approximately of 3 males to 2 females.

NUMBER OF ADULT WEEVILS ENTERING HIBERNATION.

It is evident that determinations bearing upon the number of adult weevils entering hibernation must in all cases be largely in the form of estimates because of the physical impossibility of making a thorough examination of more than a comparatively small fraction of an acre. In our own determinations upon this point we have followed the general plan of selecting average crops of plants in four or five different portions of the field, representing, so far as may be possible, different conditions in the growth of the plants which may influence the number of weevils to be found. The number of plants per acre is ultimately the basis upon which the estimate as to the number of weevils per acre is based. It is evident that the number of plants will vary widely in different localities. For example, in the river valleys, where the growth of the plants is rank, the average number may be about 5,000; whereas upon poorer land, where plants never become large, the number per acre may be as great as 10,000. From estimates made upon several hundred fields during the past two years it appears that the average number of plants per acre is not far from 7,000. We believe that this method of estimating the number of weevils per acre is more desirable and reliable than an estimation of the number of weevils per plant in which the fractions found in an average must be disregarded.

In the fall of 1903 Prof. E. D. Sanderson found from his own observations and from reports of correspondents an average of from one to two weevils per plant. In the fall of 1904 an examination of four fields at Terrell, Tex., showed a variation of between 762 and over 29,000 weevils per acre. This wide variation was due primarily to the effect of defoliation by the cotton leaf-caterpillar in one field, that having the exceptionally large number of weevils not having been defoliated. These points are mentioned particularly to show the wide variation which may occur within very short distances and also to emphasize the effect of the work of the leaf-worm in accomplishing what is practically a more or less complete destruction of the stalks.

TABLE II.—*Counts to determine number of weevils per acre at time of entrance into hibernation, in three localities in Texas.*

Date.	Locality.	Plants per acre.	Plants examined.	Weevils found.	Weevils per acre.	Remarks.
1904.						
Nov. 8	Terrell	10,890	100	267	29,076	Not defoliated by leaf-worm.
Nov. 9	do	10,890	100	61	6,643	Defoliated.
Nov. 10	do	10,890	70	5	762	Do.
Nov. 14	do	10,890	50	7	1,742	Do.
	Averages and totals.	10,890	320	340	11,570	Average four fields examined at Terrell.
Nov. 16	Calvert	7,260	30	4	968	Defoliated.
Do	do	7,260	40	79	14,338	Do.
Do	do	7,260	30	4	968	Not defoliated.
Nov. 17	do	7,260	30	9	2,178	Defoliated.
Do	do	7,260	30	39	9,438	Defoliated once.
Do	do	7,260	30	4	900	Do.
Nov. 18	do	7,260	50	21	3,049	Defoliated.
	Averages and totals.	7,260	240	160	4,840	Average seven fields examined at Calvert.
1905.						
Nov. 14	Wharton	6,200	46	47	6,355	Not defoliated.
Do	do	6,200	66	22	2,073	Do.
Do	do	6,080	5	48	58,368	Many squares.
Do	do	6,200	10	46	28,520	Do.
Do	do	6,200	10	16	1,000	Grazed by cattle.
Nov. 27	do	7,000	2	25	50,000	Estimate reduced.
	Averages and totals.	6,313	139	204	9,266	Average six fields examined at Wharton.

In connection with the work done at Dallas during the fall of 1906 repeated estimates of the number of weevils per acre to be found upon the stalks were made in the same field beginning October 12, 1906, and ending January 21, 1907. These figures are presented in Table III. The number of plants per acre in this field was 8,300.

TABLE III.—*Number of weevils per acre upon stalks at different dates at Dallas, Tex.*

Date.	Plants examined.	Living weevils found.	Living weevils per acre.
1906.			
Oct. 12	110	122	9,205
Oct. 31 to Nov. 3	84	190	18,774
Nov. 10	60	106	14,663
Nov. 20	35	29	6,877
Nov. 22	35	27	6,403
Dec. 1	36	10	2,306
Dec. 18	35	5	1,186
1907.			
Jan. 21	35	3	711

The table given above shows a number of points which are of exceptional interest. About November 1 it may be seen that the number of weevils present was more than double the number of plants. After that time there was found to be a steady decrease in the number of weevils present upon the stalks. The most abrupt change was to be found between November 10 and 20, when more than one-half of the weevils seem to have left the plants. This decrease may be attributed to several factors. First, the weevils were gradually leaving the plants through flight, which may have carried them outside the fields, and, second, many were seeking and remaining in shelter which was to be found upon the ground within the field. A hard freeze preceded by low temperatures during several days occurred on November 19. However, the examinations made on November 20 and 22 showed many weevils present in the frozen squares and especially upon the bolls. It is apparent that these weevils did not immediately leave the plants, but remained upon the bolls and squares as long as the latter might serve as a food supply. But within a few days all squares and foliage became perfectly dry, and after this especially weevils became less active. The numbers which were found upon the plants after December 1 may be considered in a rather strict sense as in hibernation. The shelter which they could obtain was comparatively slight, and in the last examination, made on January 21, about 25 per cent of the weevils found upon the bolls still hanging to the stalks were dead.

In reference to Table II attention may be called to the exceptionally large number of weevils found at Wharton in one field on November 14. This was a field of about 5 acres in extent, and at the time it was examined the plants were exceptionally large and very luxuriant in growth, showing an abundance of squares. Very few bolls had been set, so that the entire growth of the plants seems to have been turned to the production of squares. As has been shown in preceding paragraphs, such conditions would favor directly the production of an abnormally large number of weevils per acre. The fact that more than 6,000 weevils were actually collected in this field makes it even more certain that the estimate given, while possibly high, is not impossible. It may be considered as representing fully the maximum number of weevils which it is possible for an acre of cotton to support even under conditions which are most favorable to their development. Another series of examinations made before and after the freeze referred to at Dallas in a preceding paragraph should be considered in connection with Table III as serving to show the correlation between the disappearance of the weevils from the plants and their occurrence under shelter on the ground during the period when they are entering hibernation.

Table IV.—*Number of weevils under rubbish on ground at Dallas, Tex.*

Field.	Date examined.	Portion of acre examined.	Weevils found—		Total per acre.	Percentage alive.	Remarks.
			Alive.	Dead.			
	1906.						
A	Nov. 15	22 plants.	4	0	1,450	100.0	In cracks of ground around bases of plants.
A	...do	1/264	4	0	1,056	100.0	Under rubbish on ground.
A	Nov. 22	1/347	8	0	2,776	100.0	Do.
A	Dec. 18	1/264	5	14	5,016	26.3	Do.
	1907.						
B	Jan. 11	10/8384	5	2	5,870	71.4	Northeast corner of field.
C	Jan. 29	10/6236	1	1	1,247	50.0	Middle of field.
C	...do	10/8384	2	2	3,354	50.0	Near southwestern edge.

The sum total of weevils found both on plants and on the ground on November 22 shows an average of slightly more than 9,000 weevils per acre, all of which were alive. On December 18 the number that could be accounted for was between 6,000 and 7,000 per acre on the same ground which had been previously examined. On the former date more than two-thirds of the weevils were still upon the plants. On the latter date nearly five-sixths of them were on the ground and among those on the ground but 26 per cent were living. These figures show that between November 22 and December 18 a very large mortality had occurred among weevils which had entered hibernation and especially among those which had sought shelter under rubbish upon the surface of the black-waxy soil of field A.

There is some evidence indicating that there is normally a greater mortality among the weevils hibernating at the surface of heavy black soil than that occurring among weevils which hibernate on the surface of sandy soil. The reason for whatever difference there may really be in this mortality would seem to be quite directly attributable to the difference in drainage conditions in the two types of soil, and to the characteristic adhesiveness of the black type. It is quite likely that the difference is sufficient to justify different methods of treatment for the two classes, but our knowledge of the constant variations and the effective factors is not yet sufficiently complete to justify us in making specific recommendations.

TEMPERATURE CONDITIONS PRODUCING HIBERNATION.

It is evident that the exact time at which weevils begin to enter hibernation, and that at which the entrance into hibernation becomes complete, can be determined only approximately. The evidence consists largely of observations showing the decrease in the number of weevils which are active, the finding of weevils in a quiet condition within various classes of shelter, the changes in activity of weevils confined in cages, the cessation of feeding and of reproductive activity, and the general relationship of temperature to conditions of food supply and weevil activity. In the following tables are shown the maximum and minimum temperature occurring throughout the period, which has been approximately determined for each of the localities indicated in the respective seasons. The maximum temperature is given above and the minimum temperature below the line for each day. Wherever the climatic records for a particular locality are incomplete it has been necessary to use those for some other near-by locality. The table shows at a glance the daily range of temperature in each case, which undoubtedly has considerably more significance in regard to the entrance of weevils into hibernation than would the figures showing simply the mean daily temperature. The table as arranged shows a comparison of the records of all localities during each season successively.

TABLE V.—*Relation between time of entrance into hibernation and daily temperatures.*

Year.	Locality.	Period of entering hibernation.	November— 9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
1903	College Station, Tex	Nov. 15–25							85/60	83/57	70/40	58/27	45/28	51/40	59/44	68/43	74/44	72/54	66/49	60/34	61/32			
1903	Victoria, Tex. [a]	Nov. 15–30							85/50	86/52	56/45	48/32	59/32	62/36	66/39	68/42	65/45	70/45	69/52	68/38	65/33	68/38	69/37	64/39
1904	Terrell, Tex. [b]	Nov. 10–Dec. 5		53/41	51/30	57/30	70/31	72/36	77/36	79/36	48/44	82/49	76/50	71/54	68/47	80/40	85/47	84/47	77/42	74/58	64/34	80/30	74/45	80/43
1904	Victoria, Tex. [c]	Nov. 11–Dec. 8			57/42	65/32	69/36	73/37	75/38	75/40	78/42	80/48	81/51	70/61	73/58	72/55	73/53	76/50	75/50	72/51	70/47	75/42	75/45	73/46
1905	Dallas, Tex	Nov. 29–Dec. 8																					52/41	40/25
1905	Victoria, Tex	Nov. 30–Dec. 18																						55/41
1906	Dallas, Tex	Nov. 15–Dec. 8				66/33	72/34	71/38	79/39	81/62	60/57	50/44	43/33	40/28	31/25	62/25	47/40	49/43	75/47	63/46	52/45	62/46	67/45	69/53
1906	Victoria, Tex	Nov. 9–Dec. 21	83/58	84/54	83/59	83/54	67/59	73/47	77/41	80/54	75/46	70/57	59/35	62/27	65/33	58/50	73/50	87/60	74/59	72/55	57/56	70/54	74/53	79/60

Year.	Locality.	Period of entering hibernation.	December— 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1904	Terrell, Tex. [b]	Nov. 10–Dec. 5	85	80	52	43	48	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
			46	57	40	36	36																
1904	Victoria, Tex. [c]	Nov. 11–Dec. 8	77	83	65	53	47	52	65	67	....	....	....	....	....	....	....	....	....	....	....	....	....
			55	61	43	43	40	40	36	43													
1905	Dallas, Tex	Nov. 29–Dec. 8	42	51	49	57	55	52	59	64	....	....	....	....	....	....	....	....	....	....	....	....	....
			25	34	27	25	25	26	27	25													
1905	Victoria, Tex	Nov. 30–Dec. 18	57	66	51	57	59	51	61	67	67	60	51	61	58	60	63	60	65	65	....	....	....
			49	44	35	31	37	42	42	45	48	40	39	46	46	44	35	35	34	46			
1906	Dallas, Tex	Nov. 15–Dec. 8	74	68	77	73	69	58	59	69	....	....	....	....	....	....	....	....	....	....	....	....	....
			57	54	54	57	63	43	30	33													
1906	Victoria, Tex	Nov. 9–Dec. 21	80	79	82	83	83	79	71	80	81	73	65	72	80	78	65	49	46	45	47	54	75
			62	63	62	65	58	44	48	63	65	46	45	60	63	68	41	39	40	32	33	33	36

[a] Cuero, Tex., records.

[b] Corsicana, Tex., records.

[c] November records for Cuero; December records for Victoria, Tex.

This table serves to show in a graphic way the extent of the period of entrance into hibernation, the varying duration of the period for the same locality in different seasons, and the generally later date of entrance in southern localities as compared with more northern localities in the same season. It also shows the duration of the period as compared with the mean average temperature prevailing. In general it appears that the greater the drop in temperature the shorter will be the period of entrance into hibernation.

TABLE VI.—*Periods of entrance into hibernation, and temperatures.*

Year.	Locality.	Period.		Temperature.	
		Limits.	Days.	Mean average.	Effective.[a]
1903	College Station, Tex	Nov. 15–27	13	49.5	6.5
1903	Victoria, Tex	Nov. 15–30	16	53.0	10.0
1904	Corsicana, Tex	Nov. 10–Dec. 5	26	55.0	12.0
1904	Victoria, Tex	Nov. 11–Dec. 8	28	57.5	14.5
1905	Dallas, Tex	Nov. 29–Dec. 8	10	40.5	None.
1905	Victoria, Tex	Nov. 30–Dec. 18	19	50.0	7.0
1906	Dallas, Tex	Nov. 12–Dec. 8	27	53.0	10.0
1906	Victoria, Tex	Nov. 9–Dec. 21	43	60.4	17.4

[a] In studying the relationship of temperature conditions to weevil activity the term "effective temperature" is used to designate the excess of temperature above 43 degrees F. It has been estimated that 43 degrees marks approximately the beginning of activity with most animals, and experiments have shown that this is equally true of the boll weevil. Below this temperature the weevils are usually inactive. Above it they may move, feed, and reproduce with increasing rapidity as the temperature increases. From this explanation it may be readily understood that the column showing the decrease of effective temperature is really the most significant in connection with the inactivity or hibernation of the weevil.

It is undoubtedly true that minimum temperatures have a special influence in checking the activity of the weevil in spite of the fact that they may be below 43 degrees F. When the temperature falls to 32 degrees or lower the food supply of the weevils is usually rather completely destroyed, and this fact may serve to discourage subsequent activity on the part of the weevils, even though the temperature conditions might otherwise favor it.

From this table it may be seen that the shortest period of entrance into hibernation of which we have record is ten days. This occurred at Dallas, when the mean average temperature was 9 degrees lower than that for any other period which has been studied.

In regard to the limits assigned to the period for Victoria in 1906 it may be stated that hibernation was probably only partial at that place at any time during the winter of 1906–7. The limits of the period that have been given are based on field notes made about the middle of November indicating the beginning of the period, and temperature records covering the coldest period that occurred during December. The mean average temperature during November for Victoria was 60.4 degrees, the range being from an absolute minimum of 27 degrees to an absolute maximum of 84 degrees. The temperature fell below 32 degrees only once during this month. From December 1 to 21 the mean average temperature was also 60.4 degrees. In this case the range of temperature varies from an absolute maximum of 83 degrees to an absolute minimum of 32 degrees, the latter occurring only once. From these records it is apparent that the climatic conditions were not sufficiently severe either to destroy absolutely the food supply of the weevils or to insure the continued inactivity of those which may have sought shelter during the short periods of cool weather. Sprout cotton was exceptionally abundant throughout the winter and weevils were found feeding upon it almost continuously.

From these facts we may be justified in concluding that a mean average temperature of 60 degrees is too high for the complete hibernation of the weevil; that hibernation usually takes place coincidently with the decrease in mean average temperature to about 55 degrees; and that it remains complete until the mean average temperature subsequently rises to above 60 degrees.

SHELTER DURING HIBERNATION.

While many weevils seek hibernation shelter outside the field it is certain that a considerable number of them remain very near their food supply—that is, in the cotton fields and in the immediate vicinity. Because of the differences in the nature of the weevil shelter and in the possibility of destroying or removing such favorable shelter, within and without the cotton fields, these two conditions will be considered separately.

SHELTER IN BOLLS.

Within the cotton fields weevils are sheltered primarily in the hanging cotton bolls, the fallen foliage, and grass or other rubbish which may have accumulated upon the surface of the ground. Attention has already been called to the fact that many stages enter the period of hibernation in an immature condition in unopened bolls. (See p. 14.) That many adult weevils hibernate entirely within the protection afforded by the bracts and hulls of bolls has been abundantly demonstrated (Pl. II, fig. 3). Rather extensive experiments have been made upon this point in a number of localities during several seasons. The principal data resulting from these investigations are presented in the following two tables. Table VII shows a comparison of the records for several localities during four months of the winter of 1904–5. During this period the prevailing climatic conditions were the most severe that the weevil has encountered since invading Texas. The table shows therefore a gradual decrease in the number of living stages present as the season advanced.

TABLE VII.—*Decrease in percentage of stages surviving in bolls from December, 1904, to March, 1905.*

Locality.	December.							January.						
	Bolls examined.	Stages alive.				Bolls having living forms.	Forms found living.	Bolls examined.	Stages alive.				Bolls having living forms.	Forms found living.
		Larvæ.	Pupæ.	Adults.					Larvæ.	Pupæ.	Adults.			
				Not emerged.[a]	Emerged.[a]						Not emerged.[a]	Emerged.[a]		
						P. ct.	P. ct.						Per ct.	Per ct.
Terrell, Tex	300	113	30	9	0	48	92	3,678	38	16	3	6	1.98	7.3
Keatchie, La	......	......	....	......	....	......	......	1,120	3	0	2	3	.70	26.0
Dallas, Tex	......	......	....	......	....	......	......	......	....	....	......	......	......	......
Calvert, Tex	150	10	1	0	0	7	91	2,100	0	1	1	10	.50	10.0
Palestine, Tex	......	......	....	......	....	......	......	......	....	....	......	......	......	......
Victoria, Tex	......	......	....	......	....	......	......	3,257	11	7	9	18	1.37	61.0
Totals and averages	450	123	31	9	0	36	91	10,155	52	24	15	37	1.15	11.8

Locality.	February.							March.						
	Bolls examined.	Stages alive.				Bolls having living forms.	Forms found living.	Bolls examined.	Stages alive.				Bolls having living forms.	Forms found living.
		Larvæ.	Pupæ.	Adults.					Larvæ.	Pupæ.	Adults.			
				Not emerged.[a]	Emerged.[a]						Not emerged.[a]	Emerged.[a]		
						Per ct.	Per ct.						Per ct.	Per ct.
Terrell, Tex	1,500	2	2	0	0	0.26	1.5	......	....	....	......	....	......	......
Keatchie, La	1,450	2	2	1	0	.34	15	208	0	0	0	0	0	0
Dallas, Tex	......	....	....	......	....	......	......	100	0	0	0	0	0	0
Calvert, Tex	800	0	0	0	0	0	0	2,176	0	0	0	0	0	0
Palestine, Tex	......	....	....	......	....	......	......	1,599	0	0	0	0	0	0
Victoria, Tex	2,746	4	0	3	3	.36	8.6	1,438	0	(1)	0	0	0	0
Totals and averages	6,496	8	4	4	3	.29	4.1	5,521	0	1	0	0	0	0

[a] In Tables VII and IX the designation "not emerged" is used for those stages and adults which have not left the cells in which they developed. Adults which have previously left the cells within which they matured and have subsequently sought shelter within any part of the bolls are designated as "emerged."

Besides showing that large numbers of weevils entered hibernation in or upon these bolls, this table shows that bolls do not provide sufficient shelter to insure the survival of hibernating weevils in a winter so severe as was that of 1904–5.

TABLE VIII.—*Climatic conditions at Dallas, Calvert, Palestine, and Victoria, Tex., and at Keatchie, La., December 1, 1904, to March 31, 1905, producing complete mortality of weevils hibernating in bolls.*

DECEMBER, 1904.

Locality.	Temperature.					Rainfall.	
	Times below 32° F.	Absolute minimum.	Average minimum.	Monthly mean.	Departure from normal.	Depth.	Departure from normal.
		°F.	°F.	°F.	°F.	Inches.	Inches.
Dallas, Tex	15	20	33.1	46.6	− 1.2	0.74	−1.40
Keatchie, La.[a]	6	22	39.4	48.9	− .5	9.62	+4.94
Calvert, Tex.[b]	14	21	37.6	50.0	+ .1	2.58	− .04
Palestine, Tex	5	22	40.1	49.6	− 1.8	4.08	+ .27
Victoria, Tex	5	30	44.1	54.8	− 3.0	1.59	− .26
Average	9	....	38.8	50.0	− 1.3	3.70	+ .702

JANUARY, 1905.

Locality.	Times below 32° F.	Absolute minimum.	Average minimum.	Monthly mean.	Departure from normal.	Depth.	Departure from normal.
Dallas, Tex	24	12	27.8	38.7	− 6.2	3.05	+0.33
Keatchie, La.[a]	12	17	33.6	41.0	− 4.9	4.13	− .47
Calvert, Tex.[b]	13	16	34.1	44.8	− 3.1	2.01	− .44
Palestine, Tex	11	18	34.7	43.0	− 2.8	2.06	−2.25
Victoria, Tex	6	25	43.1	53.0	− .6	3.84	+1.41
Average	13	....	34.66	44.1	− 3.52	3.02	− .284

FEBRUARY, 1905.

Locality.	Times below 32° F.	Absolute minimum.	Average minimum.	Monthly mean.	Departure from normal.	Depth.	Departure from normal.
Dallas, Tex	30	2	24.6	35.2	− 9.4	2.81	+1.11
Keatchie, La.[a]	19	6	31.4	39.4	−11.8	4.12	− .04
Calvert, Tex.[b]	21	10	28.2	39.2	−10.7	3.02	+1.20
Palestine, Tex	21	6	31.9	40.0	−11.0	2.47	−1.00
Victoria, Tex	10	20	34.7	44.1	− 9.9	3.62	+1.42
Average	20	8.8	30.2	39.6	−10.6	3.21	+ .59

MARCH, 1905.

Locality.	Times below 32° F.	Absolute minimum.	Average minimum.	Monthly mean.	Departure from normal.	Depth.	Departure from normal.
Dallas, Tex	0	35	47.1	59.6	+ 4.0	4.44	+1.29
Keatchie, La.[a]	0	42	53.5	62.6	+ 5.0	5.03	+ .39
Calvert, Tex.[b]	0	35	51.6	62.1	+ 4.4	4.95	+2.34
Palestine, Tex	0	37	53.7	62.4	+ 2.5	3.95	+ .14
Victoria, Tex	0	46	57.2	65.8	+ 3.1	5.04	+3.52
Average	0	....	52.6	62.5	+ 3.8	4.68	+1.54

[a] Temperatures for Shreveport, La. [b] Temperatures for Hearne, Tex.

An examination of this table shows that the temperature went below freezing with remarkable frequency during this period. The most severe cold weather occurred during February, when the temperature averaged 10 degrees or more below normal throughout the State of Texas. The absolute minimum for this season at the five points mentioned is recorded by the Weather Bureau as being 2 degrees above zero at Dallas. At Calvert the minimum temperature was 10 degrees and at Victoria 20 degrees. In most of the localities there was an excess of rainfall, so that the winter as a whole may be characterized as having been unusually cold and wet.

While these records show that few if any weevils survived in the shelter of bolls during this season it must be remembered that the weevils were not exterminated in all of these localities. Other conditions of shelter were evidently so much more favorable than bolls as to have enabled the weevils to survive this severe winter. It is true, however, that in the spring of 1905 weevils occurred in much smaller numbers than is usually the case.

Other examinations of bolls show that in the northern portion of the infested area of Texas there is a smaller percentage of living stages in the bolls than in the southern portion. The data for three seasons are compared in Table IX. The periods selected are during the last of the winter season in each year.

TABLE IX.—*Increase in percentage of survival in bolls from northern to southern Texas.*

Section.	March, 1904.							February and March, 1905.						
	Bolls examined.	Stages alive.				Bolls having living forms.	Living forms.	Bolls examined.	Stages alive.				Bolls having living forms.	Living forms.
		Larvæ.	Pupæ.	Adults. Not emerged.	Adults. Emerged.				Larvæ.	Pupæ.	Adults. Not emerged.	Adults. Emerged.		
						Per ct.	*Per ct.*						*Per ct.*	*Per ct.*
Northern	2,600	0	0	0	0	0	0	3,258	4	4	1	0	0.27	0.026
Central	180	0	0	0	1	0.55	....	4,575	0	0	0	0	.00	.000
Southern	250	0	0	23	28	....	....	9,589	4	1	4	14	.24	.096
Brownsville	....	....	....	....	....	....	....	809	0	0	4	11	1.80	.833

Section.	February and March, 1906.							Total.	
	Bolls examined.	Stages alive.				Bolls having living forms.	Living forms.	Bolls examined.	Stages found alive.
		Larvæ.	Pupæ.	Adults. Not emerged.	Adults. Emerged.				
						Per ct.	*Per ct.*		
Northern	6,186	0	0	1	2	0.04	0	12,044	12
Central	6,650	0	0	5	11	.24	0	11,405	17
Southern	1,410	0	0	1	10	.78	0	11,249	85
Brownsville	....	......	......	......	......	....	....	809	15

It is noticeable that there is a gradual increase in the living stages from north to south, and that toward the end of the hibernation period nearly all of the living stages are adults, most of which had matured before the beginning of hibernation.

That the increased mortality found in bolls during the winter of 1904–5 can not be attributed entirely to the exceptional severity of that season is shown by the fact that a similar decrease in the percentage of living stages was found in examinations during January and February of 1906. In January among 1,933 bolls examined in several localities 86 adults and stages were found. In February 14,246 bolls were examined and only 30 adults were found. The lowest temperature experienced during January was 12° F. at Dallas, with the mean temperature of 49.6° F. in an average of the eight localities where the examinations were made. During February the absolute minimum was 15° F. at Dallas and the average minimum 38.5° F. During these two months in the localities where examinations were made the minimum temperature went below 32 degrees on an average of only nineteen days.

TABLE X.—*Climatic conditions at eight points in Texas, January to March, 1906.*

JANUARY.

Locality.	Temperature. Times below 32° F.	Absolute minimum.	Average minimum.	Monthly mean.	Departure from normal.	Precipitation. Depth.	Departure from normal.
		°F.	°F.	°F.	°F.	Inches.	Inches.
Dallas	18	12	30.8	44.4	−0.5	1.98	−0.74
Corsicana	12	19	35.4	48.6	+1.7	1.97	− .67
Hearne	15	21	36.6	49.9	+2.0	.81	−1.65
Palestine	10	21	39.2	49.6	+3.8	1.92	−2.39
Waco	11	22	36.0	51.2	+3.1	1.38	− .55
Nacogdoches	16	19	34.9	47.4	− .8	4.85	+2.11
Austin	3	26	41.6	51.4	+2.7	.81	−1.67
Victoria	3	25	42.1	54.4	+ .8	1.34	−1.09
Average	11	....	37.1	49.6	+1.6	1.88	− .83

FEBRUARY.

Locality.	Times below 32° F.	Absolute minimum.	Average minimum.	Monthly mean.	Departure from normal.	Depth.	Departure from normal.
Dallas	12	15	32.6	46.0	+1.4	2.23	+0.53
Corsicana	9	19	37.1	58.0	+1.9	2.61	+ .49
Hearne	7	23	37.2	49.4	− .5	4.22	+2.40
Palestine	7	22	38.7	48.6	−2.4	3.06	− .45
Waco	8	20	37.3	50.8	− .8	2.65	+ .72
Nacogdoches	10	20	36.7	48.2	− .4	1.73	−2.09
Austin	6	26	43.9	52.1	− .6	1.29	− .59
Victoria	5	28	44.3	54.4	+ .4	2.01	+ .19
Average	8	....	38.5	51.0	− .12	2.48	+ .15

MARCH.

Locality.	Times below 32° F.	Absolute minimum.	Average minimum.	Monthly mean.	Departure from normal.	Depth.	Departure from normal.
Dallas	11	25	38.9	50.8	−4.8	3.24	+0.09
Corsicana	5	27	39.7	49.9	−7.6	2.10	−1.25
Hearne	2	26	43.4	55.4	−2.3	1.97	− .64
Palestine	2	28	44.1	53.4	−4.2	1.24	−2.74
Waco	3	27	43.2	57.5	−1.1	2.95	− .09
Nacogdoches	3	27	44.0	54.3	−3.2	1.63	−2.82
Austin	1	32	47.8	56.8	−3.4	2.47	+ .25
Victoria	1	31	50.5	61.0	−1.7	2.24	+ .72
Average	3.5	....	44.0	55.0	−3.54	2.23	− .94

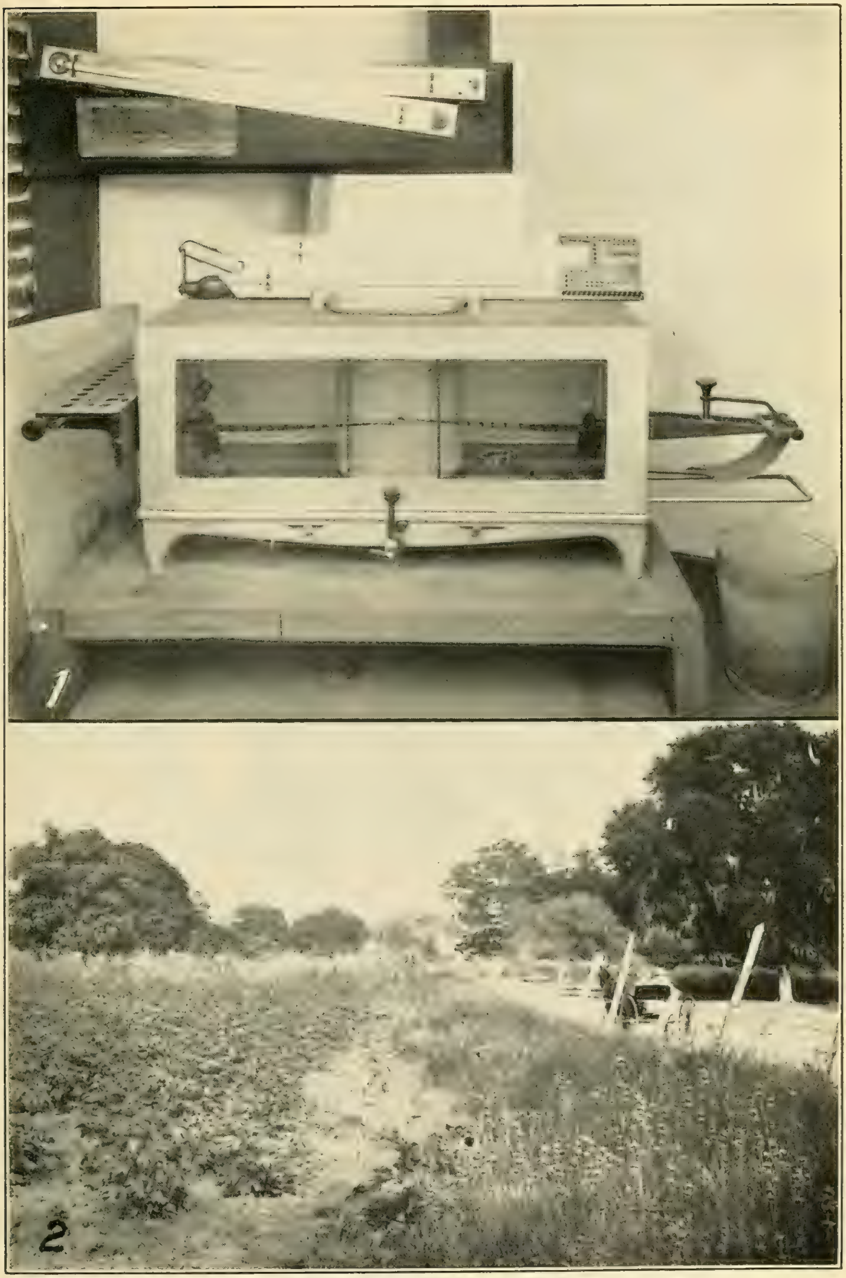
A comparison of the principal points shown in Tables VIII and X indicates the relative severity of the two seasons, especially in the columns showing absolute minimum and average minimum temperatures and departures from normal. The records for February are especially significant. In 1905 this month was unusually cold throughout the State. The absolute minimum for the five localities considered in that year was 2° F. at Dallas and the average minimum was 8.3° F. below that occurring in 1906. In 1905 the mean average temperature for the month was 10.6° F. below the normal while in 1906 it was but 0.12° F. below normal. It was during this month of extreme cold with excessive rainfall in 1905 that the greatest mortality among weevil stages occurred.

HIBERNATION SHELTER OTHER THAN BOLLS WITHIN THE FIELD.

During an ordinary season it can not be doubted that a large majority of the weevils which survive find some other shelter than the bolls hanging upon the plants. It is not, however, as easy a matter to find weevils in rubbish scattered upon the ground as in bolls. It is necessary to collect the rubbish very carefully and sift it over cloth or paper to separate the weevils from the trash. In this way it has been found that weevils hibernate extensively in the leaf and grass rubbish distributed throughout the field. Naturally the cleaner the field in the fall the smaller will be their chances of finding favorable shelter during the winter.

Standing trees are a common sight in cotton fields, and while the records of weevils found hibernating under bark are but few they are sufficient to indicate that these trees may be a rather important factor where they occur in considerable numbers. Where the Spanish moss (*Tillandsia usneoides*) (Pl. II, fig. 1) occurs, as in the bottom lands in the coast section of Texas and in the southern portions of the Gulf States, weevils find exceptionally favorable shelter within this moss. On January 18 Mr. J. D. Mitchell cut down a moss-covered tree growing in a large cotton field in the vicinity of Victoria, Tex. Between 400 and 500 pounds of moss growing on this tree was collected and examined very carefully. Three living specimens of the boll weevil were found. On February 5, 1907, a similar experiment was tried. One thousand pounds of moss was obtained from a tree standing in the midst of cotton fields. The moss was situated from 7 to 15 feet above the ground. Among a large number of other insects found hibernating in the moss there were ten living boll weevils. The weevils seem to prefer the festoons of green hanging moss to the bunches of dead matted moss (Pl. II, fig. 2).

The turnrows and ditches throughout the fields and the fence rows (Pl. I, fig. 2) surrounding them present exceptionally favorable conditions for successful hibernation. It has been noticed frequently that early in the season the most severe injury may occur on the edge of a field adjoining a fence row where weeds and grass abound.



WEATHER-RECORDING APPARATUS AND FENCE-ROW SHELTER.

Fig. 1.—Weather apparatus used in recording temperature and humidity conditions. Fig. 2.—Typical weedy fence row, affording excellent shelter for weevils. (Original.)

FAVORABLE SHELTER CONDITIONS IN AND AROUND FIELDS.

Fig. 1.—Cotton field adjoining grove of trees laden with Spanish moss (*Tillandsia usneoides*). Fig. 2.—Near view of moss. Fig. 3.—Cotton stalk having many bolls infested by weevils at hibernation time. (Original.)

One fact should be emphasized in regard to practically all classes of shelter which have been mentioned as occurring within cotton fields, i. e., that it is possible as a rule to destroy or remove practically all of them. Undoubtedly the burning of cotton stalks, weeds, grass, and other rubbish is the easiest and most effective method of destruction where it can be practiced. Next to this in importance would be the destruction of the stalks by a stalk chopper and plowing under all the rubbish. In the latter case it must be stated that many weevils which may be buried to an average depth of 2 inches will be able to escape through the soil and may then find shelter around, if not within, the field.

HIBERNATION SHELTER OUTSIDE OF COTTON FIELDS.

Unquestionably timber fringes skirting cotton fields are exceedingly important because of the shelter which the fallen leaves and undergrowth provide for weevils during the winter. The conditions to be found here are so exceedingly favorable that a majority of planters seem to recognize that the most severe infestation of young cotton in the spring may be expected to occur near such timber. Where the moss (Pl. II, fig. 1) occurs abundantly it is second only in importance to the fallen leaves as a shelter for weevils. The fact that weevils have been taken early in the spring upon trees at a distance as great as 2 miles from a cotton field shows the extent to which they may possibly scatter during the fall or seek for cotton during the spring. The planter need not, however, be alarmed by these facts, inasmuch as it is certain that but few weevils hibernating away from the immediate vicinity of cotton fields will survive to find food supply upon emergence.

Cornfields adjoining cotton or cornstalks scattered throughout cotton fields may shelter many weevils. This was first noticed by Mr. E. A. Schwarz at Victoria in the winter of 1901–2 and has since been corroborated by a number of observers. Several examinations have been made of haystacks in the vicinity of cotton. This is a task quite comparable with that of seeking for the proverbial needle and it is not surprising that the results have been very meager. The fact, however, that traces of weevils have been found in these examinations indicates that weevils may find shelter under such conditions.

Farmyards, seed houses, barns, ginneries, and oil mills also afford exceptionally favorable shelter for weevils. Especially in ginneries and seed houses (Pl. III, fig. 1) the weevils become concentrated with the concentration of the cotton or seed and frequently may be found in large numbers within or around these buildings. In connection with this subject the reader is referred to a fuller discussion of the significance of ginneries and oil mills in the distribution of weevils and of the methods recommended for controlling them which may be found in Farmers' Bulletin No. 209 of the Department of Agriculture, "Controlling the Cotton Boll Weevil in Cotton Seed and at Ginneries." Numerous observations have shown that weevils have been taken into new localities through the agency of shipments of cotton seed and cotton-seed hulls from ginneries and oil mills handling infested stock. Definite observations have been made showing that living weevils may occur in cotton seed at planting time. While it is probable that few would survive in a large mass of seed it is certain that some might do so and be distributed in the planting of the seed.

TABLE XI.—*Experiments of 1904 to 1906 to test hibernation in cotton seed.*

Locality.	When put in hiberna-tion.	Weevils put in hiberna-tion.	When exam-ined.	Weevils found alive.	Weevils found dead.
	1904.		1905.		
Terrell, Tex	Nov. 13	200	Apr. 20	0	154
Do	Nov. 30	200	Apr. 21	0	139
Do	Dec. 15	250	Apr. 22	0	170
Corsicana, Tex	Nov. 14	150	Apr. 19	0	127
Calvert, Tex	Nov. 15	200	Apr. 7	0	152
Do	Nov. 30	200	Apr. 8	0	176
Do	Dec. 15	200	...do...	0	142
Victoria, Tex	Nov. 10	200	Apr. 3	0	130
Do	Nov. 17	200	...do...	0	144
Do	Nov. 25	200	Apr. 1	0	150
Do	Dec. 1	200	Mar. 31	0	115
Do	Dec. 8	200	Mar. 29	1	149
Do	Dec. 15	200	Mar. 28	1	123
Total		2,600		[a]2	1,871
	1905.		1906.		
Dallas, Tex	Nov. 1	100	Apr. 28	0	92
Do	Nov. 18	200	Apr. 30	0	160
Do	Dec. 4	200	May 3	0	181
Do	Dec. 15	900	May 4	0	862
Total		1,400		0	1,295
Victoria, Tex	Nov. 7	100	Apr. 2	0	93
Do	...do...	100	Apr. 7	0	93
Do	Nov. 13	100	Apr. 3	0	97
Do	Nov. 30	100	...do...	0	100
Do	Dec. 11	100	Apr. 5	0	96
Total		500		0	479

[a] On January 27 47 dead and 18 living weevils were removed, and on March 4 4 dead and 1 living weevils were removed.

While the number and percentage of weevils surviving in these experiments is very small indeed, the fact that some do survive is the special point having significance. The occasional occurrence up to planting time of living weevils among seed from infested localities is alone sufficient justification for every quarantine restriction which has been placed upon cotton seed and other cotton products by uninfested territory.

The Mexican entomologist Prof. L. de la Barreda, under the direction of Prof. A. L. Herrera, of the Comisión de Parasitologia Agrícola, has made some very pertinent observations on the occurrence of boll weevils in cotton seed intended for planting.[a] In January, 1903, this entomologist examined a number of sacks of seed received from the infested area of Texas for planting in the Laguna region in Mexico. Six sacks from one consignment were selected. In these, 12 living weevils were found, together with 56 dead ones. Later examinations were made of a number of shipments of seed from the infested portions of the United States. In every case living weevils were found. This work was done in the month of January. These observations show clearly the real danger that exists in the shipment of cotton seed from infested localities to those where the weevil does not occur.

HIBERNATION EXPERIMENTS IN SMALL CAGES.

In many ways it is possible to obtain more accurate data upon hibernation of weevils through cage experiments than through field observations. In the cages conditions may be prepared which are typical of those to be found in the fields. The number of weevils within a given space can be largely increased without overcrowding, so far as the possibility of their finding shelter is concerned. The action of the weevils in seeking and in leaving shelter can be determined more accurately in cages than in the field. The food conditions may be varied to represent various field conditions and, finally, knowing definitely the number of weevils placed under certain conditions, it is possible to follow them closely enough to determine with a great deal of accuracy the proportions surviving. From a comparison of the results obtained under various experimental conditions those conditions which are most favorable as well as those which are least favorable to successful hibernation may be determined with considerable certainty. In all of our experimental work of this nature the cage results have been checked so far as has been possible by field observations.

With the continued study of the boll-weevil problem the necessity for increasingly comprehensive experiments upon hibernation has become apparent. The work thus shows from year to year a growth in complexity with the constant purpose of increasing the accuracy of results by making the experimental conditions conform as closely as is possible to field conditions. In the early stages of the work the hibernation cages were small and portable. Some were placed out of doors where they would be fully exposed to prevailing climatic conditions; others were placed in the shelter of buildings or under similar conditions where the favorable nature of the shelter provided might be determined.

[a] Boletín de la Comisión de Parasitologia Agrícola, vol. 2, No. 2, pp. 45 to 61.

CAGE EXPERIMENTS OF 1902–3.

In the experiments made during the season of 1902–3 most of the weevils used were collected in the field at Victoria, Tex., about the middle of December. Some, however, were reared weevils which during the months of September and October previous had become adult. They were confined in boxes and jars covered with cheese cloth. Various kinds of rubbish were placed in the cages, some of which were placed in the fields and some in a building.

These cages were all examined between April 15 and 30, 1903. Among the 25 lots tested, including 356 weevils, it was found that an average of about 11 per cent had survived. None of those which were adult before November 1 was living on April 15, while nearly 16 per cent of those taken in the field about the middle of December were still alive on April 27. A slightly higher percentage had survived in the inside tests, and it appears that a considerable degree of dryness favored survival. One-half of all the weevils surviving were found in the folds of dead banana leaves on April 15, while the balance were scattered among hay, dried cotton leaves, empty bolls, and in or under earth.

CAGE EXPERIMENTS OF 1903–4.

During the season of 1903–4 450 weevils were tested in lots of about 50 each. From October 21 to December 16 one or more lots were started each week, part of them being placed outdoors and part indoors. In addition to the confinement of adults, about 400 infested squares were picked from the ground about November 15 and kept until the following March. These squares were examined on March 18. It was found that most of the stages had perished while yet larvæ. Nearly one-fifth of the squares contained dead adults. In the lot among 128 stages there was one adult which was still alive.

Examination in April, 1904, accounted for all but 15 of the 450 weevils confined, but one weevil was found alive, and that one was placed in hibernation on October 29 in a cage out of doors. The results during this season seem to contradict in some respects those obtained during the preceding year, which indicated the favorable nature of inside shelter.

CAGE EXPERIMENTS OF 1904–5.

The work of the season of 1904–5 was planned to include a number of localities representing in a general way the various portions of the weevil-infested area. In all cases the cages consisted of boxes about 1 by 2 feet in size and covered with 14-mesh galvanized-wire screening. These were all placed out of doors at various dates between November 3 and December 15, 1904. The examinations were made during April, 1905.

TABLE XII.—*Summary of hibernation experiments, 1904–5.*

Locality.	Weevils put in hibernation.	Weevils found dead.	Weevils found alive.	Total number of weevils found— In grass, straw, hay, weeds, etc.	On ground.	In ground.	In banana leaves.	In excelsior.	In sorghum stalks.	In canna leaves.	In cornstalks.	In oak leaves.	In bolls cotton stalks.	In paper.	On potato vines.
Terrell, Tex	715	244	0	108	68	13	1	3	7	28	6	....	....	....	....
Paris, Tex	650	254	0	116	58	14	0	8	0	23	8	3	5	19	....
Keithville, La	489	229	0	120	68	10	0	0	0	0	4	24	3	....	....
Corsicana, Tex	572	278	0	167	60	23	....	....	....	....	21	....	5	2	....
Calvert, Tex	500	240	0	84	47	45	....	24	....	....	15	....	....	11	12
Victoria, Tex	900	601	11	190	190	6	91	....	....	....	....	48	12	....	....
Total	3,826	1,846	11	785	491	111	92	35	7	51	54	75	25	32	12

The most striking point shown in this table is the fact that no weevils survived except at Victoria. Even there the percentage was very small. Undoubtedly from 5 to 10 per cent of the weevils placed in the cages must have escaped through the wire before the season became cold enough for all to hibernate. The explanation for the death of all weevils confined north of Victoria, Tex., may be found in the exceptionally severe climatic conditions occurring during this season. These have already been indicated in Table VIII, page 27. It should be stated, however, that while weevils were scarce in the spring of 1905 in all of these localities they were not exterminated in Texas except at Paris. At this place examinations made during the season of 1905 failed to show any weevils in a field which had been quite heavily infested late in the season of 1904.

HIBERNATION EXPERIMENTS IN SMALL CAGES, 1905–6.

Tests were made at Dallas, Calvert, and Victoria, Tex., representing the northern, central, and southern sections of the infested area. Owing to the increased complexity of the experiments and the more valuable character of the results obtained, it seems advisable to present the data in a somewhat more detailed manner.

TABLE XIII.—*Summary of hibernation experiments in boxes at Dallas, Calvert, and Victoria, Tex., in 1905–6.*

DALLAS.

When put in.	Kind of rubbish.	Out-doors or in-doors.	Wee-vils put in.	When ex-amined.	Number of weevils found— Alive.	Number of weevils found— Dead.	Per-centage alive.	Remarks.
1905. Nov. 1	Corn shucks, grass, cotton leaves.	Out	100	1906. Apr. 27	0	92	0	
Do	Cotton leaves	In	100	do	0	80	0	In chicken house.
Do	do	In	100	do	0	64	0	In seed house.
Do	Sack of cotton seed	In	100	Apr. 28	0	92	0	Do.
Nov. 17	Grass, leaves, rubbish	Out	100	Feb. 19	3	82	3	
Do	do	In	100	do	0	87	0	Do.
Nov. 18	Cotton seed	In	200	Apr. 30	0	160	0	Do.
Nov. 26	Only grass	Out	200	May 1	0	165	0	
Do	Grass, seed, cotton	In	200	do	0	165	0	Do.
Dec. 4	Cotton seed	In	200	May 3	0	181	0	
Dec. 11	Corn shucks, leaves	Out	200	do	0	140	0	
Do	do	In	200	May 1	0	195	0	
Dec. 15	Cotton seed	In	900	May 4	0	862	0	300 in each of 3 sacks.
	Total	Out	600		3	479	0.5	
		In	2,100		0	1,886	0.0	

CALVERT.

When put in.	Kind of rubbish.	Out-doors or in-doors.	Wee-vils put in.	When ex-amined.	Alive.	Dead.	Per-centage alive.	Remarks.
1905. Nov. 7	Corn shucks, grass, cotton.	In	100	1906. Apr 18	0	98	0	
Do	do	Out	94	do	1	45	1	
Nov. 27	do	In	205	do	0	205	0	
Do	do	Out	200	Apr. 19	40	145	20	
	Total	Out	294		41	190	14.0	
		In	305		0	303	0.0	

VICTORIA.

When put in.	Kind of rubbish.	Out-doors or in-doors.	Wee-vils put in.	When ex-amined.	Alive.	Dead.	Per-centage alive.	Remarks.
1905. Nov. 5	Mixed	Out	100	1906. Apr. 6	2	43	2	
Nov. 7	do	Out	100	Apr. 7	1	23	1	
Do	do	In	100	do	0	73	0	
Nov. 13	do	Out	100	Apr. 4	4	53	4	
Do	do	In	100	Apr. 5	0	97	0	
Nov. 30	do	Out	100	do	1	39	1	
Do	do	In	100	do	0	94	0	
Dec. 11	do	Out	100	Apr. 7	3	51	3	
Do	do	In	112	do	4	100	3.57	
	Total	Out	500		11	209	2.2	
		In	412		4	364	.97	
	Total of 3 localities	Out	1,394		55	878	3.9	
		In	2,817		4	2,553	.14	

In the small-cage experiments of 1905–6 but three localities were tested. In the 26 experiments were placed 4,211 weevils, of which number 1,394 were out of doors and 2,817 indoors. In only one cage did weevils survive within doors, and that was at Victoria, where it would seem that such protection was least needed. The two most striking results were the small survival at Dallas and the remarkably large survival in one of the outdoor experiments at Calvert. In the outdoor tests an average of 3.9 per cent survived, while in the others but 0.14 per cent survived. In an average of all tests the survival was 1.4 per cent.

The nature of the shelter failed to show any significant influence in these small-cage experiments.

The relative favorableness of outside conditions is shown in the following table by a comparison of the data in each of the three localities. This table does not include the experiments with cotton seed:

TABLE XIV.—*Comparison of survival records outdoors and indoors for three Texas localities in 1905–6.*

Locality.	Outside. Weevils put in hibernation.	Outside. Weevils survived. Number.	Outside. Weevils survived. Percentage.	Inside. Weevils put in hibernation.	Inside. Weevils survived. Number.	Inside. Weevils survived. Percentage.
Victoria, Tex.	500	11	2.2	412	4	0.97
Calvert, Tex.	294	41	14.0	305	0	0
Dallas, Tex.	600	3	.5	2,100	0	0
Total	1,394	55	3.9	2,817	4	0.14

During this season it is very evident that in all localities outdoor conditions were decidedly more favorable for successful hibernation. Upon the average the survival out of doors was twenty-eight times as successful as in the tests made indoors.

Grouping the experiments according to fifteen-day periods from November 1 to December 15, when they were instituted, the most favorable time for entering hibernation seems to be indicated.

TABLE XV.—*Comparative favorableness of periods for entering hibernation, 1905.*

Locality.	Nov. 1–15, 1905. Weevils put in hibernation.	Nov. 1–15, 1905. Weevils survived. Number.	Nov. 1–15, 1905. Weevils survived. Per cent.	Nov. 15–30, 1905. Weevils put in hibernation.	Nov. 15–30, 1905. Weevils survived. Number.	Nov. 15–30, 1905. Weevils survived. Per cent.	Dec. 1–15, 1905. Weevils put in hibernation.	Dec. 1–15, 1905. Weevils survived. Number.	Dec. 1–15, 1905. Weevils survived. Per cent.	Total survival. Number.	Total survival. Per cent.
Victoria, Tex.	500	7	1.4	200	1	0.5	212	7	3.3	15	1.60
Calvert, Tex.	194	1	.5	405	40	10.0				41	6.80
Dallas, Tex.	300	0	.0	600	3	.5	400	0	0	3	.23
Total	994	8	.8	1,205	44	3.7	612	7	1.1	59	2.10

This table does not include the experiments in cotton seed. The comparisons show that during the fall of 1905, November 15 to 30 was more favorable than either an earlier or later period at Calvert and Dallas, while at Victoria the period between December 1 and 15 was more favorable.

The shelter conditions within which weevils survived was also determined in these experiments, and the principal points are shown in the following table, which again does not include cotton-seed tests:

TABLE XVI.—*Shelter in which surviving weevils were found in April and May, 1906.*

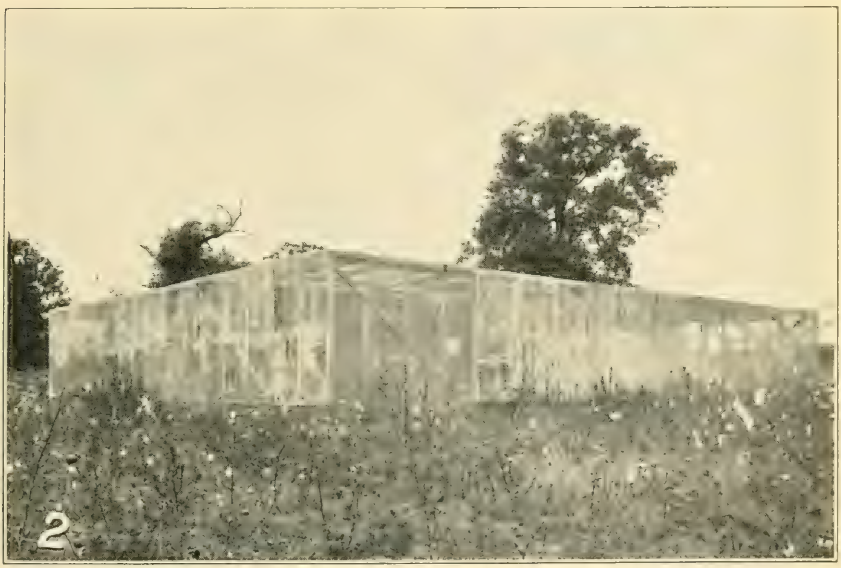
Locality.	Bermuda grass and hay.	Excelsior.	Paper.	Banana leaves.	Corn shucks, old cotton stalks, and bolls.	Total.
Victoria, Tex	5	4	1	1	4	15
Calvert, Tex					41	41
Dallas, Tex	3					3
Total	8	4	1	1	45	59

This shows the favorable nature of old corn and cotton stalks, among which the survival in one cage at Calvert was surprisingly large. It also indicates that weevils may survive in varied shelter, and that in all probability the temperature and moisture conditions experienced may be as important as the nature of the shelter in determining survival.

LARGE-CAGE EXPERIMENTS, KEATCHIE, LA., 1905-6.

With the work of 1905–6 a change was made in the method of carrying on the hibernation experiments. Instead of using numerous small boxes in a number of places, large screen-covered cages were utilized in the fields at Keatchie, La., and Dallas, Tex. The Keatchie cage (Pl. III, fig. 2) was constructed under the direction of Mr. Wilmon Newell, secretary of the State crop pest commission of Louisiana and special field agent, cooperating in the boll weevil investigations. It was probably the largest structure of its kind that has ever been built for an entomological investigation. The interior was divided by partitions into eighteen sections. The shelter conditions for the weevils and the dates upon which weevils were inclosed were planned to represent the extremes of field conditions as to shelter and date of entrance into hibernation. The general plan of the experiment is shown in the first section of Table XVII, and in the last section are included the emergence records for the cage.

Before entering upon a discussion of the work at Keatchie special credit should be given Mr. Wilmon Newell and his assistant, Mr. J. B. Garrett, who were particularly concerned in the execution of the work at Keatchie. Much work has also been done by Mr. W. D. Hunter upon the reports of the Keatchie experiments in arranging the data so as to show the most significant facts.



SEED HOUSE AND HIBERNATION CAGE, KEATCHIE, LA.

Fig. 1.—Seed house opposite which the first sign of weevil work was found at Keatchie, La., in 1905. Fig. 2.—Large cage built for hibernation experiments in 1905-6. (Original.)

TABLE XVII.—*Summary of installation and emergence records in cage at Keatchie, La.*

Installation records, 1905.					Emergence records, 1906.					
Section number.	Where weevils were collected.	When weevils were put in.	Number of weevils put in.	Shelter in cage section.	March.		April.		May 1-14.	
					Number.	Per cent.	Number.	Per cent.	Number.	Per cent.
1..	Louisiana.	Nov. 29	1,200	Brush, leaves, moss, stumps, logs; stalks removed.	2	0.166	3	0.25	4	0.33
2..	...do.......	Nov. 25	1,000	Same, but stalks standing.........	0	....	7	.7	10	1.0
3..	...do.......	...do.....	1,000	Cotton seed piled; plants left standing.	1	.1	4	.4	0	....
4..	...do.......	...do.....	1,000	Same, but seed left uncovered....	2	.2	5	.5	0	....
5..	...do.......	...do.....	1,000	Absolutely bare..................	1	.1	1	.1	0	....
6..	Texas.....	Nov. 23	1,000	Ordinary field....................	5	.5	18	1.8	4	.4
				Stalks, grass, etc.:						
7..	...do.......	Nov. 29	2,100	Same as 1.......................	2	.09	17	.81	16	.76
8..	...do.......	Nov. 25	1,500	Same as 2.......................	2	.14	33	2.2	15	1.0
9..	...do.......	...do.....	1,000	Same as 3.......................	2	.2	9	.9	3	.3
10..	...do.......	...do.....	1,000	Same as 4.......................	2	.2	15	1.5	0	....
11..	...do.......	...do.....	1,000	Same as 5.......................	0	....	10	1.0	4	.4
12..	...do.......	Nov. 23	1,000	Same as 6.......................	0	....	17	1.7	12	1.2
13..	Louisiana.	Dec. 18	1,000	Stalks left; leaves, etc., added; shaded.	1	.1	2	.2	1	.1
14..	Texas.....	Dec. 3	4,000	Same as 13, but not shaded........	4	.1	29	.72	17	.42
15..	...do.......	...do.....	4,000	Same as 14.......................	9	.22	94	2.35	28	.7
16..	...do.......	Dec. 8	1,000	.....do..........................	1	.1	15	1.5	5	.5
17..	Louisiana.	Nov. 28	1,000	.....do..........................	4	.4	17	1.7	10	1.0
18..	...do.......	Nov. 18	1,000	Check on 13; stalks, grass, leaves, not shaded.	0	....	15	1.5	8	.8
Totals and averages.			25,800	....	38	.18	311	1.2	137	.53

Installation records, 1905.					Emergence records, 1906.				Rank of section based on per cent of survival.
Section number.	Where weevils were collected.	When weevils were put in.	Number of weevils put in.	Shelter in cage section.	March 1 to May 14.		Total number emerged.	Total per cent of survival.	
					Number.	Per cent.			
1..	Louisiana.	Nov. 29	1,200	Brush, leaves, moss, stumps, logs; stalks removed.	9	0.75	26	2.16	11
2..	...do.......	Nov. 25	1,000	Same, but stalks standing......	17	1.7	25	2.5	9
3..	...do.......	...do.....	1,000	Cotton seed piled; plants left standing.	5	.5	6	.6	16
4..	...do.......	...do.....	1,000	Same, but seed left uncovered.	7	.7	8	.8	15
5..	...do.......	...do.....	1,000	Absolutely bare...............	2	.2	4	.4	17
6..	Texas.....	Nov. 23	1,000	Ordinary field..................	27	2.7	38	3.8	6
				Stalks, grass, etc.:					
7..	...do.......	Nov. 29	2,100	Same as 1.....................	35	.66	44	2.09	13
8..	...do.......	Nov. 25	1,500	Same as 2.....................	50	3.33	64	4.26	3
9..	...do.......	...do.....	1,000	Same as 3.....................	14	1.4	17	1.7	14
10..	...do.......	...do.....	1,000	Same as 4.....................	17	1.7	22	2.2	10
11..	...do.......	...do.....	1,000	Same as 5.....................	14	1.4	26	2.6	8
12..	...do.......	Nov. 23	1,000	Same as 6.....................	29	2.9	55	5.5	1
13..	Louisiana.	Dec. 18	1,000	Stalks left; leaves, etc., added; shaded.	4	.4	8	.8	15
14..	Texas.....	Dec. 3	4,000	Same as 13, but not shaded....	50	1.25	86	2.15	12
15..	...do.......	...do.....	4,000	Same as 14.....................	132	3.3	170	4.25	4
16..	...do.......	Dec. 8	1,000	.....do........................	21	2.1	35	3.5	7
17..	Louisiana.	Nov. 28	1,000	.....do........................	31	3.1	41	4.1	5
18..	...do.......	Nov. 18	1,000	Check on 13; stalks, grass, leaves, not shaded.	23	2.3	53	5.3	2
Totals and averages.			25,800	....	487	1.5	728	2.82	....

The beginning of this work occurred so late in November that none of the sections can be considered as having been placed in hibernation early. Cold weather occurred between about November 30 and December 3, during which time the majority of weevils entered hibernation. Emergence appears to have begun on March 22, and the last weevils emerged on June 28. The emergence during April and May was quite uniform, while during June it decreased rather steadily. In these records no allowance has been made for the escape of weevils through the wire on the cage. Using the number placed in the cage (25,800) as a basis, the 728 weevils which emerged constitute a survival of 2.82 per cent. It is impossible to call attention to all of the many interesting points shown in this table. Special emphasis, however, will be given several points through the rearrangement of the significant data in succeeding tables.

Since climatic conditions are primarily responsible for hibernation and the emergence of weevils therefrom, the records should be studied in relation to a chart of the temperature conditions, such as is given in figure 1. No climatic records are available for Keatchie previous to the beginning of these observations upon March 15. The emergence of weevils may well be shown in relation to the range in temperature upon the same chart. In studying the effects of temperature variations upon weevil activity it has been found that those temperatures which are about 43° F. alone produce activity among the weevils. Because of this fact 43° F. is regarded as the starting point in emergence records, and all temperatures above 43 degrees may be spoken of as "effective temperatures" upon the following diagram; the average between the maximum and minimum extremes for the day is recorded as the mean average temperature. While it is probably true that maximum temperatures have a special significance in their effect upon emergence from hibernation, and that minimum temperatures have a special effect upon entrance into hibernation, it will be more simple and sufficient in this study to use the single line representing mean average temperature during the emergence period.

From this diagram it will be seen that the emergence at Keatchie in 1906 occurred practically during four rather clearly defined periods. These periods are separated by marked declines in the mean average temperature. It will be noticed that as it became warmer following these cold periods there was an increased emergence of the weevils. After the middle of May so large a proportion of the living weevils had emerged that the number recorded became gradually smaller, although the temperature rose still higher.

Some of the special facts demanding attention are those relating to the effect of the various conditions of shelter upon the survival of weevils, the relation of emergence to effective temperature in various periods, the relation of the time of putting into hibernation to the time of emergence therefrom, the relation of accumulated effect-

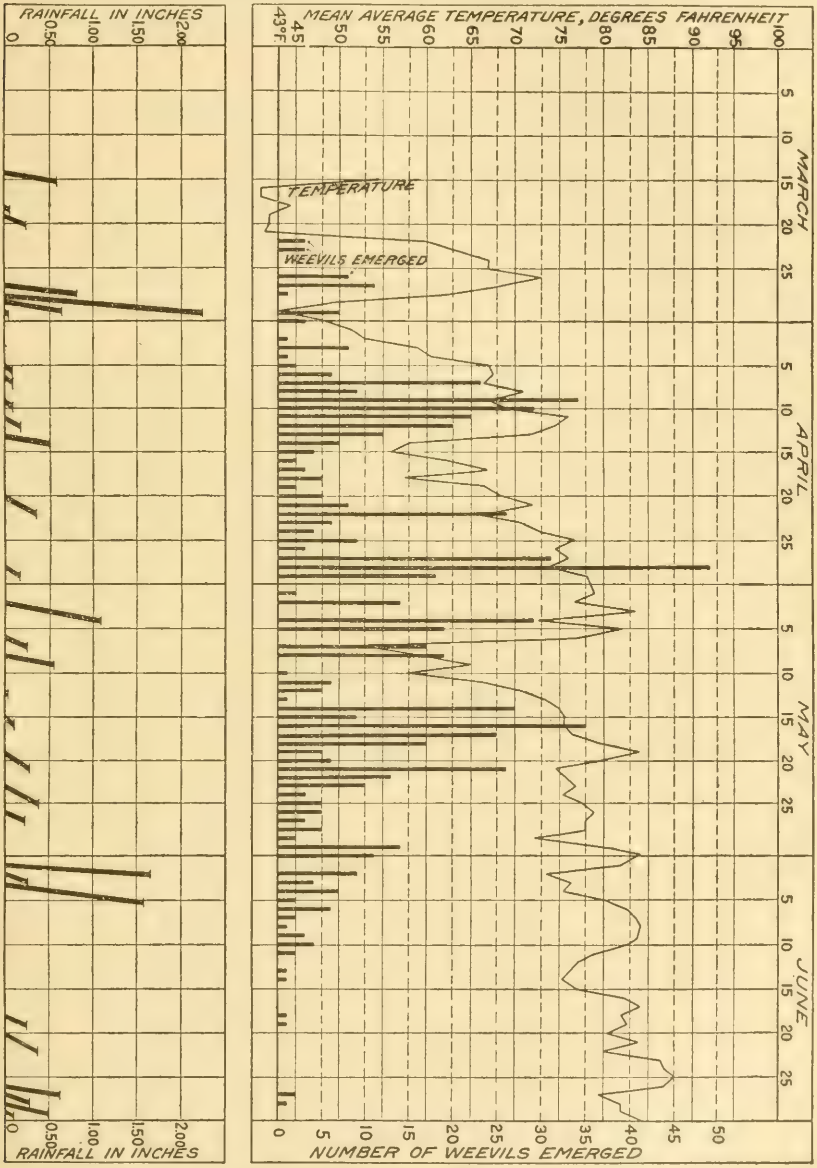


Fig. 1.—Chart showing mean average temperature, rainfall, and weevil emergence, Keatchie, La., March to June, 1906.

ive temperatures to emergence, and the longevity of the emerged weevils. These subjects will be considered under succeeding topics.

FAVORABLE CONDITIONS FOR HIBERNATION.

For a study of favorable conditions for hibernation those sections have been selected which are most strictly comparable in respect to the time weevils were placed therein, the source of the weevils, and the nature of the shelter. Practically one-half of the weevils used were collected in Texas and sent to Keatchie for this work. The sections used in this comparison received weevils between November 23 and 29.

TABLE XVIII.—*Favorable conditions for hibernation determined by rank in percentage of weevils surviving at Keatchie, La., in 1905–6.*

Section number in cage.	Nature of shelter.	Weevils put in.	Weevils survived.		Rank of section.
			Number.	Per cent.	
6 and 12	Ordinary field stalks, grass, etc	2,000	93	4.65	1
2 and 8	Brush, leaves, stumps, logs; stalks standing	2,500	99	3.56	2
1 and 7	Same as above, but stalks removed	3,300	70	2.12	3
4 and 10	Cotton seed, piled but uncovered; stalks standing	2,000	30	1.50	4
5 and 11	Absolutely bare ground	2,000	30	1.50	4
3 and 9	Cotton seed piled and covered; stalks left standing	2,000	23	1.15	5

It is evident that ordinary field conditions where stalks are allowed to stand together with the grass and leaves littered over the ground are as favorable for successful hibernation as any conditions. It must be admitted that the shelter conditions in the bare sections (5 and 11) are not such as would occur in a field plowed in the fall because of the fact that the inclosed weevils could still find shelter in the structure of the cage itself. This will undoubtedly explain the survival of 1.5 per cent in two sections having no rubbish on the ground. It is apparent, however, that even with this advantage of cage structure over bare ground, slightly more than three times this percentage of weevils survived where ordinary field conditions existed. Without the shelter afforded by the cage this difference would undoubtedly be very much greater. In 9 sections which contained rubbish, among 15,500 weevils, 567, or 3.66 per cent, survived. The shelter may therefore be held accountable for increasing the survival at least 2.1 per cent. Thus upon an area where no more than 15 weevils might survive without protection, 36 at least might be expected to survive with the protection.

EFFECT OF ACCLIMATIZATION UPON SURVIVAL AND EMERGENCE.

It has already been mentioned that about one-half of the weevils used in this work were collected in Texas and one-half at Keatchie, La. In order to determine whether this difference in the geographical section in which the weevils developed might exert an influence upon their survival and emergence the records for a number of comparable sections are combined. These weevils were all placed in hibernation between November 25 and 29, 1905.

TABLE XIX.—*Comparison of emergence records at Keatchie, La., for weevils collected in Louisiana with those collected in Texas.*

Date.	Percentage of emergence during each month based upon total emergence of— 6,200 weevils collected in Louisiana.		Percentage of emergence during each month based upon total emergence of— 6,600 weevils collected in Texas.	
1906.				
March	9.09		4.6	
April	33.63		48.6	
May 1-14	21.82	50	21.9	42.2
May 15-June 1	28.18		20.3	
June 2-30	7.28		4.6	
	100.00		100.0	

Altogether in these sections 110 of the Louisiana weevils and 173 of the Texas weevils emerged, making a percentage of total survival in the former case of 1.77 and in the latter case of 2.62. On the whole the Texas weevils emerged slightly earlier than did those collected in Louisiana, but the records are too nearly similar to indicate that such would regularly be the case.

RELATION OF EMERGENCE TO EFFECTIVE TEMPERATURES.

The practical point in these studies of temperature and emergence relationships is to ascertain the facts upon which emergence depends, so that it may be possible from a study of temperature records for any locality to form fairly reliable conclusions as to the effects which those temperature conditions may have had upon weevil activity. In this way it may be possible to determine approximately the time when weevil emergence begins, the time when the majority of weevils will probably have left their hibernation quarters, and approximately the time at which emergence becomes complete. In this connection it will be profitable to compare the records for Dallas, Tex., with those for Keatchie, La., for the same periods.

The total effective temperature is obtained by computing the sum of the mean average effective temperatures for each of the days included within the period shown. For example, if the mean average temperature for the first day of a period is 60° and for the second day 68°, the average effective temperature for the two days is 17° and 25°, respectively. The sum of these, or 42°, is the total effective temperature for those two dates.

TABLE XX.—*Relation of effective temperatures to emergence at Keatchie, La., and Dallas, Tex., 1906.*

Periods of emergence.	Total effective temperature.		Average effective temperature.		Number of weevils emerging.	
	Keatchie.	Dallas.	Keatchie.	Dallas.	Keatchie.	Dallas.
	°F.	°F.	°F.	°F.		
Mar. 15-21	12.0	5.5	1.7	0.78	0	0
Mar. 22-27	141.0	151.8	23.5	25.3	25	2
Mar. 28-Apr. 2	37.0	66.6	7.4	11.1	12	0
Apr. 3-13	275.5	243.6	25.0	22.14	165	28
Apr. 14-20	118.5	124.1	16.9	17.7	28	0
Apr. 21-May 5	484.7	435.8	32.3	29.0	187	18
May 6-13	176.0	159.8	22.0	19.9	49	0
May 14-23	339.0	300.2	33.9	30.0	173	7
May 24-29	201.0	196.8	33.5	32.8	23	0
May 30-June 11	413.0	478.0	37.5	....	65	....
June 12-30	667.0	700.0	39.2	....	7	....

An examination of this table shows three very distinct periods of emergence, the first being from April 3 to 13, inclusive; the second from April 21 to May 5, inclusive; and the third from May 14 to 23. No weevils emerged from the Dallas cages after May 23. At Keatchie a fourth period may be considered as occurring between May 30 and June 11. In this place the emergence ceased on June 28. It is noticeable that between June 20 and 27 no weevils had emerged. It will be noticed in the table that the periods of largest emergence are separated by periods having decidedly lower temperatures, during which emergence was decreased, although it did not cease entirely.

The relation of emergence to 5-degree increments in effective temperature is shown in Table XXI.

TABLE XXI.—*The relation of emergence to increase in effective temperature at Keatchie, La., and Dallas, Tex., 1906.*

Range of effective temperatures.	Keatchie, La.		Dallas, Tex.		Total number of weevils emerged.	Per cent, based on grand total emerged.
	Number of weevils emerging.	Per cent of total emergence.	Number of weevils emerging.	Per cent of total emergence.		
1-14°	20	2.7	0	0	20	2.5
15-20°	52	7.1	2	3.6	54	6.8
21-25°	116	16.0	25	45.5	141	17.8
26-30°	127	17.5	18	32.7	145	18.5
31-35°	309	42.4	10	18.2	319	40.7
36-40°	84	11.5	0	0	84	10.7
41-50°	20	2.7	0	0	20	2.5
Total.	728	100.0	55	100.0	783	100.0

The number of weevils emerging under 14 degrees of effective temperature, or 57° F., is very small indeed. From that point the emergence increases with the increase in temperature until after a majority of the weevils have emerged. Most weevils left their winter quarters during an effective temperature averaging between

21 and 35 degrees. At Keatchie 75 per cent and at Dallas 96 per cent of the total emergence took place between these limits. At Dallas the largest emergence occurred between 21 and 25 degrees of effective temperature, while at Keatchie the largest emergence occurred between 31 and 35 degrees.

In considering the effect of temperature upon emergence it must be remembered that the nature of the shelter within which the weevil hibernates must inevitably have an important bearing on the time at which the weevil becomes active.

RELATION OF TIME OF ENTRANCE INTO HIBERNATION TO SURVIVAL AND EMERGENCE.

It has previously been stated that none of these experiments was instituted more than about a week before it became cold enough for practically all weevils to hibernate. For this comparison it is possible to use only the data for those sections having similar conditions as to (1) the source from which weevils were obtained, (2) the time when they were placed in the cage, and (3) the general nature of the shelter afforded.

TABLE XXII.—*Relation of time of emergence in 1906 to time of starting hibernation in 1905.*

Section number in cage.	When weevils were put in.	Percentage of total emergence, 1906, occurring in—					Per cent of survival.	Remarks.
		March.	April.	May 1–14.	May 15–June 1.	June 2–30.		
7 and 8	Nov. 25 and 29.	3.7	46.3	28.7	15.7	5.5	3.0	Texas weevils.
14, 15, and 16.	Dec. 3 and 8.	4.8	47.4	17.1	24.7	5.5	3.23	Texas weevils.
17	Nov. 28	9.7	41.4	24.4	22.0	2.4	4.1	Louisiana weevils.
18	Nov. 18	0	28.3	15.0	32.0	24.5	5.3	Louisiana weevils.

In the first section of the table, among weevils collected in Texas, it is apparent that there was practically no difference in the time of emergence between those placed in hibernation from November 25 to 29 and those started December 3 to 8. In the second part of the table, among the Louisiana weevils, those entering hibernation November 18 emerged more slowly than did those placed in the cage November 28. The explanation of this may probably be found in the fact that the first date was not sufficiently early to insure the death of many weevils by starvation before they could hibernate. It did, however, allow a larger proportion of them to penetrate deeply into the shelter than in the case of weevils placed in the cage ten days later, which was only one day before a marked decrease in temperature. The weevils placed in the cage on December 3 and 8 experienced warmer temperatures than those placed in on the 28th of November, and, therefore, found conditions more favorable for their entrance into hibernation. The records indicate that there is a most favorable time for entrance during which weevils may find shelter from which they will emerge rather later than the average during the following spring.

THE RELATIONSHIP OF ACCUMULATED EFFECTIVE TEMPERATURE TO EMERGENCE.

In studying the relationship of accumulated effective temperature to emergence the initial point has been set arbitrarily at February 1. It would be both interesting and profitable if we could determine positively the exact effective temperature conditions under which emergence from hibernation begins. This point will be further discussed in the light of the additional records obtained in Texas in 1907.

The object in this particular study is to determine the relation of accumulated effective temperature to the accumulation in emergence. The records for both Keatchie and Dallas are included for the sake of comparison.

TABLE XXIII.—*Relation of accumulated effective temperature to the beginning and accumulation of emergence, Keatchie, La., and Dallas, Tex.*

Periods of emergence.	Accumulated effective temperature.		Accumulated number of weevils emerged.		Accumulated percentage of total emergence.	
	Keatchie.	Dallas.	Keatchie.	Dallas.	Keatchie.	Dallas.
1906.	°*F.*	°*F.*				
Feb. 28	145.6	208.6	0	0	0	0
Mar. 1–14	282.1	325.0	0	0	0	0
Mar. 15–21	294.1	330.5	0	0	0	0
Mar. 22–27	435.1	482.3	25	2	3.4	3.6
Mar. 28–Apr. 2	472.1	548.9	37	2	5.0	3.6
Apr. 3–13	747.6	792.5	202	30	27.5	54.5
Apr. 14–20	866.1	916.6	230	30	31.3	54.5
Apr. 21–May 5	1,350.8	1,362.4	417	48	56.8	87.2
May 6–13	1,526.8	1,512.2	466	48	63.4	87.2
May 14–23	1,865.8	1,812.4	639	55	87.0	100.0
May 24–29	2,066.8	2,009.2	662	55	90.0	....
May 30–June 11	2,479.8	2,487.6	727	55	99.0	....
June 12–30	3,146.8	3,188.0	734	55	100.0	....

Emergence at Dallas became complete with the accumulation of slightly over 1,800 degrees of effective temperature, while at Keatchie complete emergence required slightly over 3,000 degrees of effective temperature. At Dallas 87 per cent of weevils had emerged when 1,512 degrees of effective temperature had accumulated and the same percentage had emerged at Keatchie with 1,865 degrees effective temperature. For the last 13 per cent of weevils emerging but 300 degrees of temperature accumulated at Dallas, while at Keatchie nearly 1,300 degrees accumulated. It is probable that at Dallas during this season the emergence in the cage was completed somewhat sooner than would have been the case normally, on account of the late period of starting the experiments.

At Victoria in the spring of 1904 the period of emergence from hibernation was determined in the field under exceptionally favorable conditions. A severe drought, occurring immediately after most of the cotton had been planted, so retarded germination that the sprout cotton developed nearly two months in advance of the planted. Large numbers of weevils emerged before most of the planted cotton was through the ground. Practically the only food supply afforded these weevils was found in the sprout cotton. By reducing the number of sprout plants upon a field of 65 acres it was possible to examine at frequent intervals all of the plants. Since all weevils found at each examination were collected and removed from the field those found at the next subsequent examination may be considered as having emerged in the interval. The development of squares upon the most advanced plants was not sufficient to make it possible for any weevils of the first generation to have become adults before June 1. The collections from the sprout plants were continued until May 26, and it is probable that some weevils emerged from hibernation after this date. Our knowledge of the weevils at that time was not such as to enable us to distinguish accurately between hibernated and recently emerged adults after that date. For that reason May 26 was considered as representing the conclusion of emergence from hibernation, although it probably continued longer.

TABLE XXIV.—*Relation of accumulated effective temperature to accumulated emergence in field observations at Victoria, Tex., in 1904.*

Periods.	Accumulated effective temperature.	Accumulated number of plants of cotton sprouts examined.	Accumulated percentage of plants examined to entire number examined.	Accumulated number of weevils found.	Accumulated percentage of weevils at each date to entire number found.
	°F.				
Feb. 1-28	508.0	None.	None.	None.	None.
Mar. 1-18	585.5	250	4.2	19	2.93
Mar. 19-25	1,117.5	650	11.0	39	6.01
Mar. 26-31	1,240.0	1,190	20.1	65	10.03
Apr. 1-5	1,378.5	1,720	29.1	100	15.40
Apr. 6-12	1,537.0	2,120	35.9	160	24.60
Apr. 13-16	1,656.0	2,320	39.3	200	30.80
Apr. 17-May 1	2,104.0	2,570	43.5	224	34.50
May 2-11	2,374.0	2,990	50.6	376	58.00
May 12-19	2,584.0	4,163	70.5	521	81.00
May 20-26	2,814.5	5,900	100.0	648	100.00

A comparison of Tables XXIII and XXIV shows that there was a much greater accumulation of temperature at Victoria for the same percentage of emergence than occurred at either Dallas or Keatchie, although the Keatchie record appears to exceed the Victoria record in the amount of accumulated temperature accompanying complete emergence. It seems very probable that in the field records the accumulations are excessive because of two facts; first, at each examination all weevils were considered as emerging upon the date of the examination, whereas in the cages the weevils were collected daily. The second reason is that upon plants in the field there was a much greater possibility of overlooking weevils which were present and which might be found and counted as having emerged upon some succeeding examinations. Table XXIV is, however, of value in supporting the records given in Table XXIII, especially because similarly favorable conditions for determining the full period of emergence in the field may rarely occur.

LONGEVITY OF WEEVILS AFTER EMERGENCE IN KEATCHIE EXPERIMENTS.

For determining longevity after emergence the weevils emerging during short periods were placed together in a smaller cage provided with a variety of rubbish but with no food. Examinations of the small cages were made at frequent intervals and the period between the average date when weevils were placed in the cage and the average date of examinations was recorded. The figures are arranged chronologically according to emergence.

TABLE XXV.—*Longevity of weevils after emergence from hibernation, without food, at Keatchie, La., 1906.*

Date of emergence.	Number of weevils emerged.	Weevil-days.[a]	Average number of days lived.	Date of emergence.	Number of weevils emerged.	Weevil-days.[a]	Average number of days lived.
1906.				1906.			
March 26	1	62.0	62.0	May 7	16	292.5	18.2
April 10	44	905.5	21.7	May 8	16	262.0	16.3
April 11	35	751.0	21.4	May 10	1	1.0	1.0
April 12	29	678.5	23.4	May 11	6	54.5	9.0
April 13	8	261.0	32.6	May 12	5	13.0	3.2
April 14	7	169.0	24.1	May 13	1	1.5	1.5
April 15	5	100.5	20.1	May 14	8	58.5	7.3
April 16	2	59.0	29.5	May 15	2	26.0	13.0
April 17	....	....	....	May 16	13	169.5	13.0
April 19	2	55.0	27.5	May 17	6	58.0	9.6
April 20	11	119.0	10.8	May 18	4	48.5	12.1
April 21	9	92.0	10.2	May 22	2	23.5	11.7
April 22	23	378.5	16.4	May 23	2	29.0	14.5
April 23	6	132.5	22.0	May 25	2	26.5	13.2
April 24	4	36.0	9.0	May 28	1	1.5	1.5
April 25	9	83.5	9.2	May 29	1	7.5	7.5
April 26	3	24.0	8.0	May 30	4	35.0	8.7
April 28	46	855.0	18.5	June 9	1	7.0	7.0
April 30	18	313.0	17.3	June 19	1	4.0	4.0
May 1	2	15.0	7.5				
May 2	15	173.0	11.5	Totals and average	418	7,155.0	17.11
May 4	28	431.0	15.3				
May 5	19	342.0	18.0				

[a] In the third column of the table the expression "weevil-days" is used to signify the total number of days lived by the total number of weevils recorded for a certain date. For example, if one weevil had lived 10 days, a second 15 days, and a third 23 days the total number of weevil-days for these 3 individuals would be 48 and the average number of days lived would be 16.

It is noticeable that weevils emerging early in the season survived far longer than the average period, while those emerging toward the end of the season survived for less than the average period. For the 418 weevils tested the average duration of life without food proved to be slightly over seventeen days.

LARGE-CAGE EXPERIMENTS AT DALLAS, TEX., 1905-6.

The work at Dallas for 1905-6 was planned especially to check the results of the experiments at Keatchie which have been described. The cage used (Pl. IV, fig. 1) was divided into four sections, each having a ground area of 100 square feet. In one section the natural conditions of shelter were left unchanged (Pl. IV, fig. 2). There was practically no grass upon the ground, but the growth of stalks was quite heavy. In the other three sections the shelter provided (Pl. V, figs. 1 and 2) for the weevils was arranged in such a way that it might be possible to divide each section into two parts by a middle partition. Unfortunately the first cold weather occurred before the weevils could be placed in these sections, and it was necessary to keep the weevils confined in boxes for several days until it became sufficiently warm to render them active so that they might find shelter in the cages. The weevils were liberated at approximately the center of each section and allowed to move in any direction they might choose. The object of this was to determine whether particularly favorable rubbish might exert a special attraction for the weevils.

About three weeks after the weevils were liberated an examination was made of each section and the number of weevils crawling actively upon the wire was determined. An examination of the boxes from which the weevils were liberated and which had been left undisturbed in the cages during this period showed that a large mortality had occurred before the weevils really entered hibernation. Table XXVI shows the principal points in regard to the beginning of the experiments and the emergence of the weevils during the following spring.

TABLE XXVI.—*Large-cage experiments in hibernation at Dallas, Tex., 1905-6.*

Section of cage.	Kind of shelter.	Weevils put in.	Active weevils, December 26, 1905.	Weevils found dead, December 26, 1905.	Percentage of weevils active, December, 1905.	Percentage of living among those examined.	Date of first emergence, 1906.	Day of largest emergence, 1906.
I	Cotton stalks	2,600	375	615	14.4	38.0	Apr. 4	May 2
II:								
Pt. 1	Cotton stalks removed March 22, 1906.	2,500	200	515	8.0	28.0	Mar. 22	Apr. 9
Pt. 2	Cotton stalks and leaves.						Apr. 4	Apr. 11
III:								
Pt. 1	Bare	2,500	260	1,205	10.4	17.7	Apr. 23	Apr. 23
Pt. 2	Hay						May 14	May 14
IV:								
Pt. 1	Piled boxes	2,500	238	1,625	9.5	12.7	Apr. 4	Apr. 11
Pt. 2	Corn and cotton stalks.						Apr. 9	Apr. 9
	Total and average.	10,100	1,073	3,960	10.6	21⅓		

TABLE XXVI.—*Large-cage experiments in hibernation at Dallas, Tex., 1905-6*—Con.

Section of cage.	Kind of shelter.	Emergence by periods.							Total survival.	Percentage of survival.	Rank of cages on basis of survival.
		Mar. 22-31.	Apr. 1-10.	Apr. 11-20.	Apr. 21-30.	May 1-10.	May 11-20.	May 21-31.			
I	Cotton stalks	0	1	2	4	4	2	0	13	0.5	2
II:											
Pt. 1	Cotton stalks removed March 22, 1906.	2	3	0	3	0	0	0	8	1.04	4
Pt. 2	Cotton stalks and leaves	0	6	7	3	1	1	0	18	......	1
III:											
Pt. 1	Bare	0	1	0	1	0	0	0	2	.12	5
Pt. 2	Hay	0	0	0	0	0	1	0	1	......	7
IV:											
Pt. 1	Piled boxes	0	4	3	2	0	1	2	12	.56	3
Pt. 2	Corn and cotton stalks	0	2	0	0	0	0	0	2	......	6
	Total and average	2	17	12	13	5	5	2	56	.5	

The division of sections 2, 3, and 4 was made by inserting a partition of cheese cloth early in the spring of 1906 before any weevils became active. The percentage of survival has been based upon the total number of weevils placed in the four sections. It should be borne in mind that the conditions at the time of entrance into hibernation were decidedly unfavorable for the weevils, as is shown in the fact that about 35 per cent had died before December 26 and under such conditions as to indicate that they were very weak at the time they were placed in the cage. No allowance has been made for the escape of weevils through the wire. It thus appears that approximately 1 per cent of the weevils which really may be said to have entered hibernation survived and emerged between March 21 and May 31. The survival in the bare section was less than one-fourth of the smallest survival in the sections provided with rubbish. For the sake of comparison with the records at Keatchie, La., some data from the Dallas experiments have been used in connection with those at Keatchie in several of the tables which have already been given.

NATURE OF WEEVIL ACTIVITY FOLLOWING EMERGENCE FROM HIBERNATION.

In following the activity of emerged weevils it was deemed advisable to pursue a very different method at Dallas from that which has been described at Keatchie. Instead of removing weevils from the sections in which they had emerged, each weevil was marked in such a way as to make it possible to recognize it individually and the weevils were allowed to remain practically undisturbed in the section where they had spent the winter. In making the daily examinations record was kept of the appearance or disappearance of each individual weevil. No food was supplied in any of the sections until

HIBERNATION EXPERIMENTS, DALLAS, TEX., 1905-6.

Fig. 1.—Four-section cage used for experiments, built over cotton. Fig. 2.—Shelter conditions as occurring naturally in section 1. (Original.)

SHELTER CONDITIONS IN DALLAS, TEX., EXPERIMENTS, 1905-6.

Fig. 1.—Piled cotton stalks and piled boxes in section 2. Fig. 2.—Standing cotton stalks versus piled leaves, section 3. (Original.)

toward the close of the experiments in May, when seed was planted and cotton began growing before the last weevils emerged. Some very interesting results were obtained from this method of observation. A majority of the weevils were seen a second time, and some disappeared and reappeared as many as eight times. The longest period between the first and second appearances of any individual was forty-three days.

TABLE XXVII.—*Intermittent activity of unfed weevils after emergence, at Dallas, Tex., 1906.*

Number of weevils seen—								Weevils "rehibernated"—						Average survival, number of days.
								Once.		Twice.		Three times.		
Once.	Twice.	Three times.	Four times.	Five times.	Six times.	Seven times.	Eight times.	Number.	Days.	Number.	Days.	Number.	Days.	
46	26	15	11	6	2	2	1	17	8.7	6	7.2	2	3.5	6.8

As has been previously shown, entrance into hibernation is a gradual process and weevils which have first become quiet may subsequently become active and seek other shelter before finally hibernating. In a very similar way emergence from hibernation is gradual but extended throughout a longer period of time than is entrance into hibernation. The observations recorded in Table XXVII also show conclusively that weevils may leave their winter quarters during warm days and, failing to find food, they may again become quiet and emerge again after a considerable interval. This fact has an important bearing upon the proposition which is frequently advanced by planters of starving the weevils in the spring by deferring the time of planting. While many weevils might perish in this way, it is certain that many more would be able to survive and reappear at intervals, so that there would be plenty of weevils to infest the crop, even though this might be planted as late as is possible to secure any yield.

Other observations were made upon the intermittent activity of unfed weevils during the spring of 1906. Weevils from Calvert, Victoria, and Brenham, Tex., were tested. The weevils from Calvert and Victoria, Tex., had been confined in hibernation cages throughout the winter. Those from Brenham were collected in the field early in March. None of these weevils had tasted food after emergence. In these tables the date of death, unless otherwise indicated, is considered as having been the middle date between the last examination at which a weevil was found alive and that at which it was found dead.

TABLE XXVIII.—*Intermittent activity of unfed emerged weevils, 1906.*

Locality.	When collected.	When put in hibernation.	When removed from hibernation.	When rehibernated.	Weevils put in rehibernation.	Date of first examination.
	1905	1905	1906	1906		
Calvert, Tex.	Nov. 25	Nov. 27	Apr. 19	Apr. 23	20	May 10
Victoria, Tex.	Nov. 7, 13 Dec. 11	Nov. 7, 13 Dec. 11	Apr. 6	Apr. 16	7	Apr. 24
	1906					
Brenham, Tex.	Nov. 1		Mar. 1	Mar. 7	8	May 11

Locality.	Weevils surviving.	Date of second examination.	Weevils surviving.	Date of third examination.	Weevils surviving.	Date of death of longest survival.	Average length of life in rehibernation.
							Days.
Calvert, Tex.	10	May 22	6	June 8	0	June 8	30.4
Victoria, Tex.	3	May 10	0			May 10	19.1
Brenham, Tex.	2	May 23	1	May 31	0	May 31	67.4

The records for Calvert and Brenham show a very remarkable power of endurance in some weevils, the average survival for the two lots of 20 and 8 weevils being over thirty and sixty days, respectively.

CLIMATIC CONDITIONS PRODUCING EMERGENCE FROM HIBERNATION AT DALLAS, TEX., IN 1906.

In the figure given below, representing climatic conditions and the emergence at various dates, the temperature line given represents only the mean average effective temperature.

In this case, as at Keatchie, the emergence occurred especially during four well-defined periods and the conclusions stated in connection with figure 1 apply equally well to the results shown in figure 2.

EMERGENCE IN THE FIELD AT VICTORIA, TEX., IN 1906.

The observations upon emergence in the field at Victoria, Tex., in 1906, were begun too late in the spring to indicate the limits of the first part of the period of emergence. For this work a field of about one-half acre was selected in which it was apparent early in May that there would be a large number of hibernated adults. The observations were planned to furnish information particularly upon two points under field conditions: (1) The determination of the period of emergence and (2) the period of activity of emerged weevils. The work was done by Mr. A. C. Morgan, who devoted particular attention to a study of this field throughout the season of 1906. The method followed was to examine every plant and every square or boll throughout this area. After the first two examinations had been made it became apparent that some method must be adopted to enable the weevils found at each examination to be distinguished. At each subsequent examination, therefore, the weevils found were marked with a paint of a different color. Early in the season the weevils emerging from hibernation were sufficiently numerous to practically prevent the setting of fruit upon this area. The first weevils of a new generation did not begin to appear until

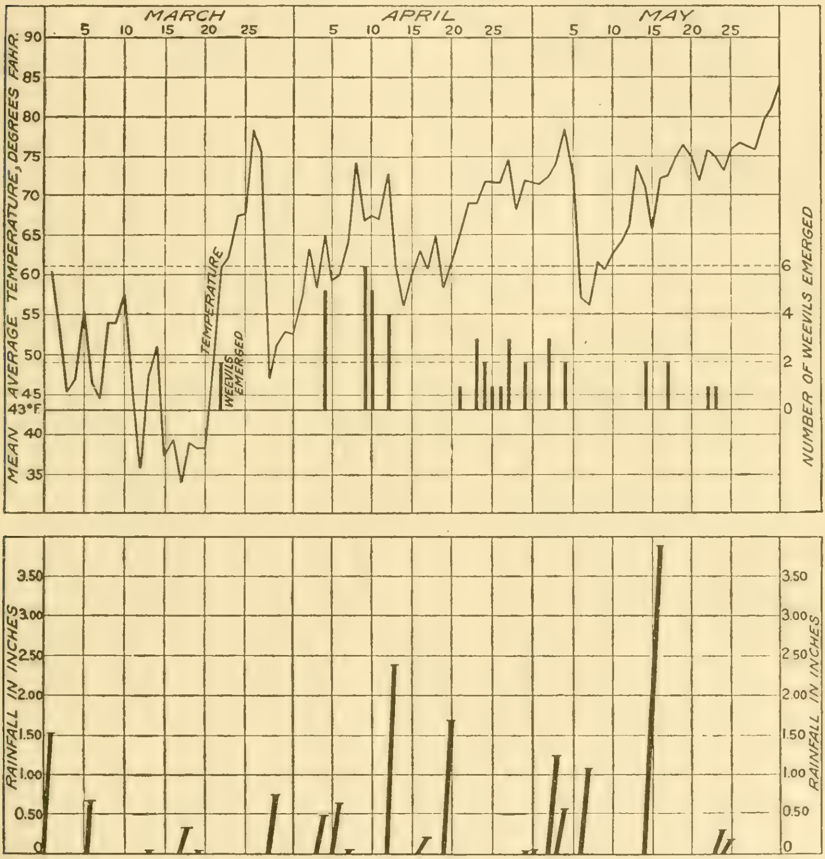


FIG. 2.—Chart showing mean average temperature, rainfall, and weevil emergence, Dallas, Tex., March to May, 1906.

about June 20. It was then easily possible to distinguish between hibernated adults and those which were not more than two or three weeks old. It is probable that the oil paints which were used may have been responsible for the death of many of the weevils marked, since it was hardly possible in the field to apply the paints with the necessary care.

TABLE XXIX.—*Emergence records for one-half-acre field at Victoria, Tex., 1906.*

Date of examination.	Number of weevils found. Unmarked.	Marked yellow. ♂	Marked yellow. ♀	Marked blue. ♂	Marked blue. ♀	Marked red. ♂	Marked red. ♀	Total number found.	Remarks.
1906.									
May 19	346	....	....	....	....	....	....	346	Weevils not removed.
May 25	358	....	....	....	....	....	....	358	Do.
May 28.[a]									
June 3–5	492	....	....	....	....	....	....	492	Weevils marked yellow=492.
June 13	226	129	....	....	....	....	....	355	Weevils marked blue=226.
June 23–July 5	165	27	9	18	9	....	....	228	Weevils marked red=87.
July 23–26	731	3	0	0	1	2	2	739	Weevils marked white=78.
Total	2,318	159	9	18	10	2	2	2,518	

[a] Eighty-seven weevils removed from field May 28 for other experimental work.

It is evident from an examination of the number of weevils found that the number in the field increased steadily until after June 5. Between June 5 and 13 a large number of previously marked weevils appeared, all of which were undoubtedly hibernated. The very small number of first-generation weevils which was found upon the examination made between June 23 and July 25 was due primarily to the exceptionally severe hot dry weather which had prevailed for several weeks. The gradual decrease in the number of living hibernated weevils was greater than the increase in the number of first-generation weevils. During the period between the middle of June and the middle of July the plants rapidly increased their fruiting activity and there was a decided decrease in weevil injury. It is interesting to note that in spite of the large number of hibernated weevils occurring in this field, which threatened early in the season to prevent entirely the setting of fruit, the weevil injury and development were so checked by the heat and drought that after the middle of July these plants set fruit rapidly and the field produced an average yield of cotton.

The most plausible explanation of the late period of emergence for weevils found in this field is the existence in its immediate vicinity of a large number of trees which were loaded with long Spanish moss. (See Pl. II, figs. 1, 2.) The explanation of the effect of this moss in producing late emergence from hibernation will be considered more particularly in connection with the cage experiments in hibernation for 1906 to 1907.

LARGE-CAGE EXPERIMENTS, DALLAS, CALVERT, AND VICTORIA, TEX., 1906-7.

PLAN OF EXPERIMENTS.

Profiting by the work done during former seasons, plans were made by Mr. W. D. Hunter, in charge of the investigations, for much more careful and extensive work during the winter of 1906-7 than had ever been undertaken. Three localities for the experimental work were selected representing in a general way the northern, central, and southern sections of the State. In these localities, also, much work had previously been done and the results for more than one season could therefore be used in a comparative way. At Dallas, Calvert, and Victoria screen-covered cages were erected, each being 20 feet wide, 50 feet long, and about 6½ feet high. (Pl. VI, figs. 1, 2, and 3.) These cages were divided into ten sections by partitions, each section having a ground area of 100 square feet. The three localities selected offered a considerable range in geographical and climatic conditions. Each section of the cage was provided with a door opening to the outside through which access could be had to a section without disturbing the conditions in any other section. It was planned to provide similar conditions of shelter in corresponding sections and to confine weevils in corresponding sections at as nearly the same date as might be possible in each of the three sections. The weevils used were collected in the immediate locality where they were placed in hibernation. In this way it was anticipated that data might be obtained bearing especially upon the following points:

(1) The effect of the time of entrance into hibernation upon the survival of weevils. In the experiments first started it was necessary to force entrance into hibernation, if possible, or starvation by the destruction of the food supply. The geographical range was expected to increase the interval between the beginning of the experiment in each locality and the time when weevils would normally hibernate.

(2) The effect which the complete destruction of food supply at varying dates might have upon the success of hibernation. For these experiments the shelter conditions were as uniform and as favorable as it was possible to make them in the different localities. It was hoped through these tests to determine the minimum interval which must elapse between the destruction of stalks and the successful hibernation of the weevils.

(3) To determine the effect of exceptionally favorable and unfavorable conditions of shelter upon the hibernation of weevils placed in the cages upon the same date. It was intended that the shelter conditions provided should be so exaggerated as to represent the extremes of conditions which might naturally occur in the field.

(4) To determine the effect which different depths and classes of shelter might exert upon the success of hibernation and also upon the time of emergence and the range of the emergence period.

(5) To test the power of adaptation which the weevils might have acquired to varying climatic conditions by bringing weevils from widely separated localities for comparison with weevils collected at Dallas. In each test similar conditions of food and shelter should exist in each locality.

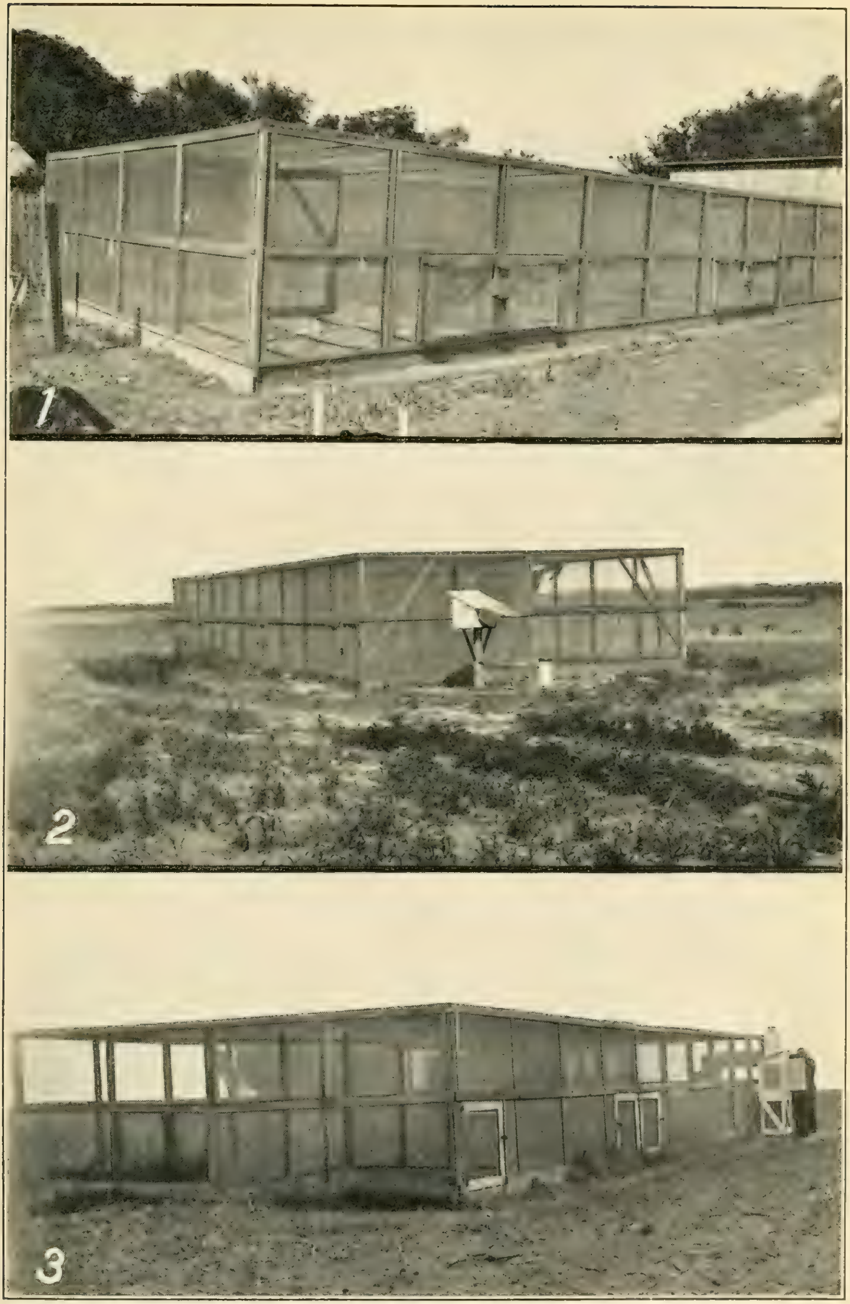
(6) To determine upon a large scale, in very widely separated localities, the proportion of weevils entering hibernation which might survive.

(7) To determine the relation between climatic conditions and the emergence period in each locality. To provide suitable and reliable data for this study, standard Weather Bureau instruments were secured and temperature, humidity, rainfall, and other records were kept in each locality throughout the period covered by the experiments.

(8) To determine the longevity of hibernated weevils, especially after emergence. Since all weevils used in this work were collected promiscuously in the field immediately preceding their confinement in the cages, all figures showing their longevity must be based either upon the date when they were placed in hibernation or upon the date of their emergence. In the latter case it would be distinguished as longevity after emergence.

It was planned to use from 2,500 to 3,000 weevils in each section of the cages, although difficulties in the collection of the desired number for the particular dates when experiments were to be started occasionally caused some variation in this number. Adult weevils only were used in sections 1 to 9, inclusive, in each cage, while in section 10 the hibernation of weevils in bolls was tested. One-half of the bolls were buried under 2 inches of dirt. The other half were exposed upon the surface of the ground. (Pl. X, fig. 1.)

It is generally understood that the principal factor producing a hibernation period is the lower temperature occurring during the fall and winter months. In its effect upon the survival during this period moisture is also an important factor. As a rule, in studies of these factors investigators have been obliged to rely upon the climatic reports published by the United States Weather Bureau for the particular locations desired. It happens frequently, however, that there may be no report from the Weather Bureau for the particular locality desired. Both temperature and rainfall are liable to considerable variation within comparatively short distances. In order that the data for these studies of the hibernation of the boll weevil might be complete and thoroughly reliable, we have kept full climatic records in the immediate vicinity where experiments and cage obser-



CAGES FOR HIBERNATION EXPERIMENTS IN TEXAS, 1906-7.

Fig. 1.—Dallas, Tex., cage on flat, black-waxy land. Fig. 2.—Calvert, Tex., cage on slightly sloping, sandy land in post-oak region. Fig. 3.—Victoria, Tex., cage on sandy-loam slope between bottom and upland. (Original.)

vations have been made. The instruments used are of standard Weather Bureau type (Pl. I, fig. 1) and, as the records extend over several years, reliable data have been secured upon the following climatic factors which may affect hibernation: Maximum and minimum temperatures supplemented by a continuous temperature record made by a recording thermograph; the actual rainfall as measured in a standard type of rain gauge; the atmospheric moisture existing at 8 or 9 o'clock a. m. and 5 to 6 o'clock p. m., supplemented by a continuous record of the moisture in the air furnished by a hygrograph.

TABLE XXX.—*Outline of hibernation experiments in 1906-7.*

No. of section.	Date of starting experiments in 1906.			Character of shelter supplied.	Food supply.
	Dallas.	Calvert.	Victoria.		
1	Oct. 13	Oct. 13	Oct. 25	Leaves and grass, 4 to 5 inches ...	All food removed after two days.
4	Oct. 16	Oct. 19	...do....	......do	Stalks cut down and left to dry.
2	Oct. 19	Nov. 26	Oct. 28	......do	All food removed after two days.
7	Oct. 25	Oct. 25	Nov. 6	Spanish moss hung on string at top of cage; loose bark on ground.	Stalks cut down and allowed to dry.
8	Oct. 31	Oct. 31	Nov. 10	Leaves and grass 4 to 5 inches deep.	All food removed after two days
5	Nov. 6	Nov. 5	Nov. 14	......do	Cotton cut down and allowed to dry.
3	Nov. 12	Nov. 14	Nov. 21	Leaves and grass, 2 inches	Do.
9	...do.....	Nov. 12	...do.....	Leaves and grass, 10 inches	Do.
6	Nov. 28	Nov. 25	Nov. 28	Ground absolutely bare	No food supply.
10	Dec. 6 and 10.	Dec. 3	Nov. 29	(a)	

[a] In this section, 3 bushels of probably infested bolls were exposed on the surface of the ground in one half of cage, and 3 bushels were buried under 2 inches of dirt in the other half.

The dates given in Table XXX are the actual dates of beginning the experiment in each locality. The arrangement of the experiments shown in the table is primarily chronological, without regard to the sequence in the number of sections. Some knowledge of the plan of this work is essential to a clear understanding and a correct interpretation of the results obtained from it.

CLIMATIC CONDITIONS PRODUCING HIBERNATION AND ACTIVITY OF WEEVILS DURING NORMAL HIBERNATION PERIOD.

The climatic records are started with October 1, 1906, in order to show a comparison between temperature conditions under which weevils are normally very active with those under which they become inactive. The termination of what is considered as being the hibernation period is rather arbitrarily set at the time when weevils begin to emerge in considerable numbers. It should be stated that in each locality the climatic records for the winter of 1906 were very unusual. The principal points of variation will be noted in subsequent paragraphs in their most important connections. In each chart (figs. 3-5) showing temperature conditions it has been deemed advisable to show only the line representing the mean average temperature.

While it is probable that a study of maximum and minimum temperatures is really more accurate, from a scientific point of view, the mean average temperature, representing one-half of the sum of the maximum and minimum for each day will be sufficiently exact and a more simple manner of expressing the relationship existing between temperature and weevil activity. The significance of the term "effective temperature" has previously been explained (p. 24). Upon the temperature charts the line representing 43 degrees is therefore exceptionally emphasized. Wherever the temperature line is above this point it represents effective temperature. Whenever it falls below the 43-degree line it is possible that frosts may occur if other atmospheric conditions are coincidently favorable.

Whenever the minimum is noted to be 32 degrees or below, the actual temperature occurring is given in its appropriate place upon the record. When the temperature rises above 80 degrees, establishing a new maximum, the occurrence is also shown by the actual record given upon the charts.

Since it is impossible for weevil emergence to occur at any temperature below 43 degrees, that point is considered as initial in the lines giving the records of the activity of weevils. The actual number of weevils found active at various dates is shown at the top of the line in each case.

ENTRANCE INTO HIBERNATION.

In each locality there occurred a considerable decrease in temperature during the month of October, the minimum being reached about the 31st. This, however, was not sufficiently cold to cause weevils to hibernate in considerable numbers. During the following two weeks the temperature ranged as high as the average for October. After November 15, however, there occurred a very marked fall of temperature, the minimum even as far south as Victoria establishing itself at about 25 to 27 degrees. All cotton was killed by this freeze. The count of weevils found active early in November indicated merely that few weevils had entered hibernation at that time. Further counts, made about November 30, showed that even so severe a drop in temperature as had occurred did not immediately drive weevils into hibernation. During the succeeding two or three weeks the temperature again ranged fully as high as during October, and apparently many weevils which had sought shelter after the freeze of the night of November 19 again became active. This was indicated by the large number of weevils found active at Calvert and Victoria about December 10. About the middle of December another period of low temperature occurred, which was followed by decreased activity among the weevils, many of which did not, even then, seek shelter. During the first three weeks of January the exceptionally warm weather experienced throughout Texas drew a considerable number

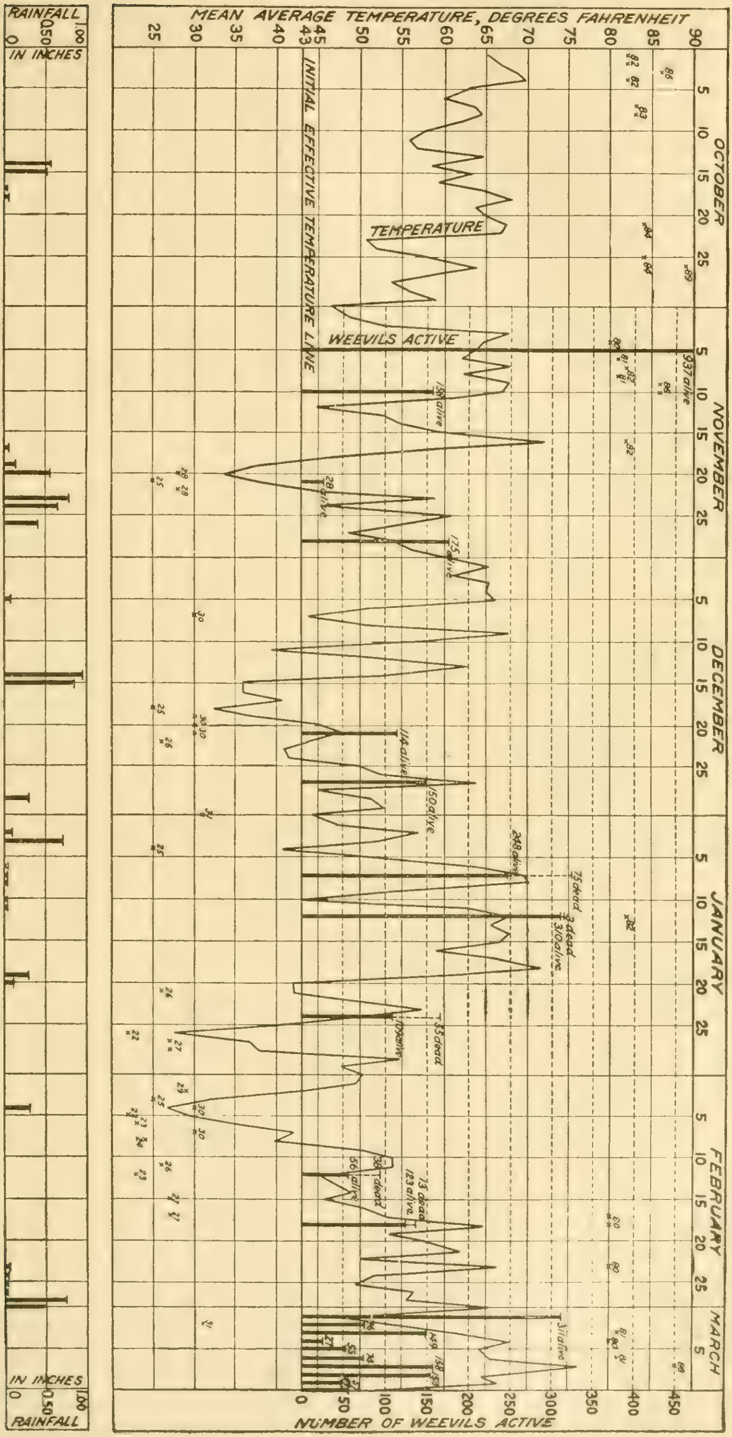


FIG. 3.—Chart showing mean average temperature, rainfall, and weevil activity, Dallas, Tex., October, 1906, to March, 1907.

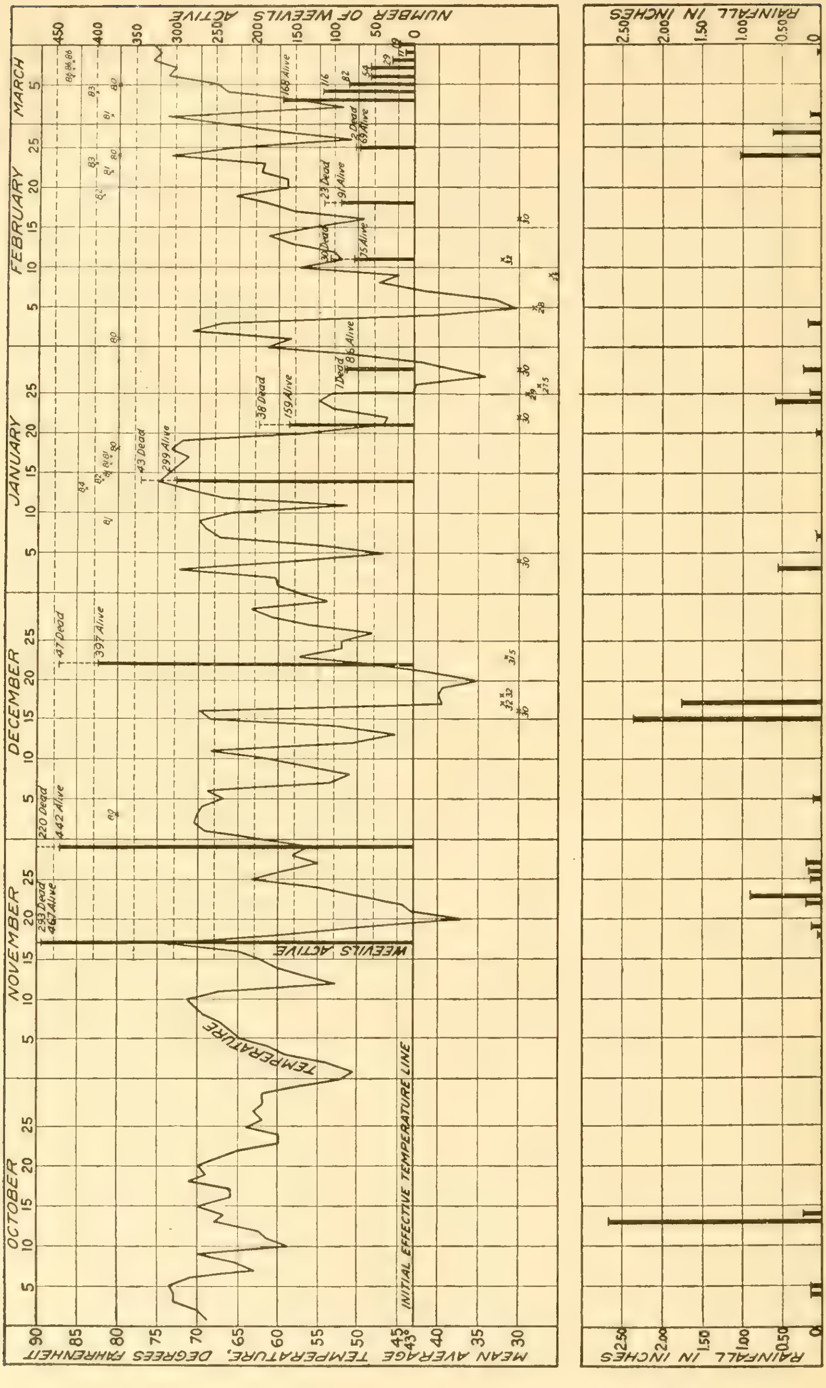


FIG. 4.—Chart showing mean average temperature, rainfall, and weevil activity, Calvert, Tex., October, 1906, to March, 1907.

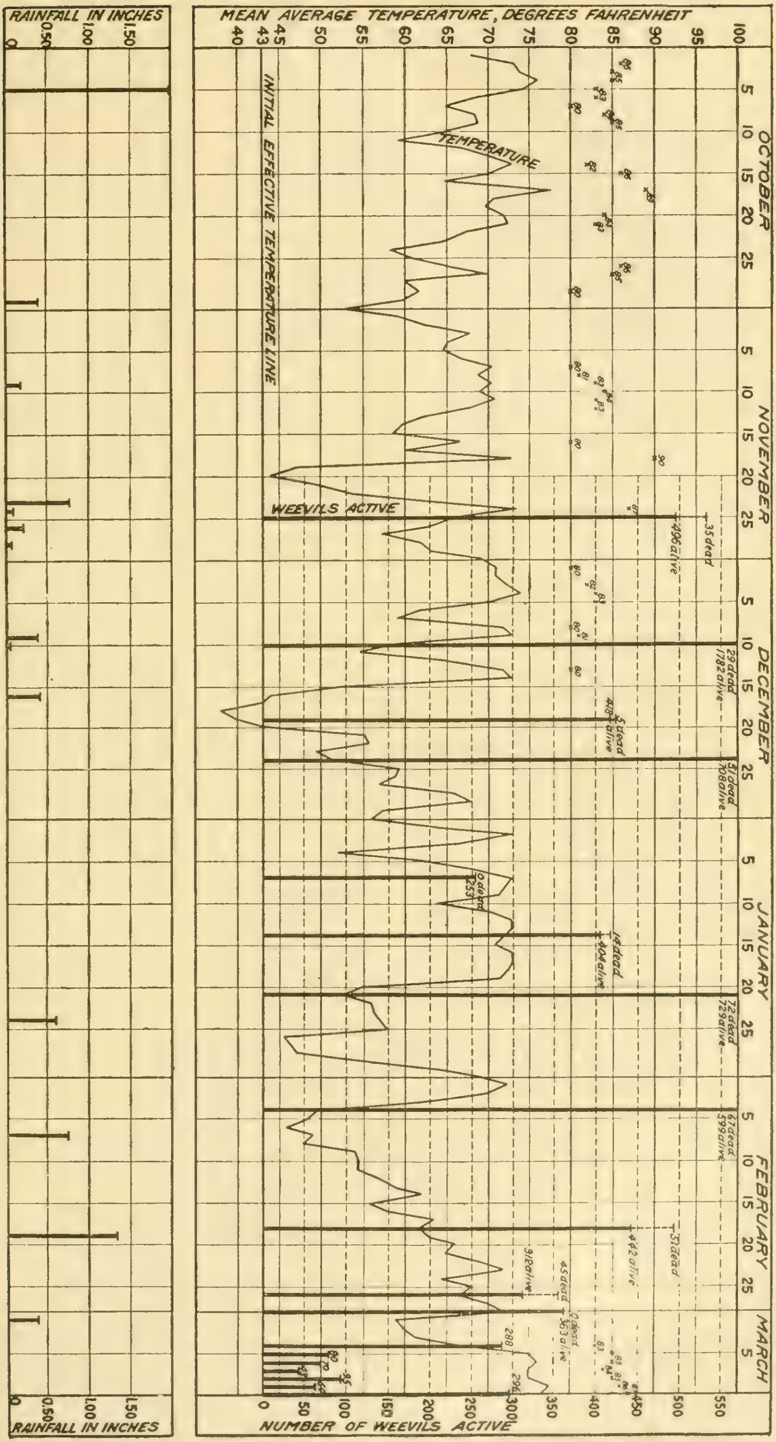


FIG. 5.—Chart showing mean average temperature, rainfall, and weevil activity, Victoria, Tex., October, 1906, to March, 1907.

of weevils from shelter. During the last week of January and the first week of February the lowest temperatures of the winter occurred at Dallas and Calvert. The counts made immediately after this period showed the smallest number of active weevils recorded at any time during the winter for those two localities. At Victoria the temperature was not sufficiently low to produce any marked decrease in weevil activity. During the remainder of February there was a rather steady rise in temperature throughout the State and many weevils continued active. The figures show that during the last week of the month considerable numbers were emerging from their winter shelter; and beginning with March 1 the period of general emergence is considered to have begun.

While these three charts show plainly the conditions existing during the winter of 1906–7, proving beyond question that during this season there was no such thing as complete hibernation of the boll weevil in Texas, it must not be understood that this is frequently the case. No other such season has occurred since the weevil entered Texas. As a rule, hibernation is complete during the period of from four to six months. It is certain that weevils may continue their activity throughout the season wherever climatic conditions are not sufficiently severe to entirely destroy the growth of cotton.

ACTIVITY DURING NORMAL PERIOD OF HIBERNATION.

The general impression as to the activity of weevils during the normal period of hibernation has been shown in figures 3 to 5. A summary of the records for the three locations, with the temperature conditions prevailing at the time of each examination, is shown in Table XXXI.

TABLE XXXI.—*Activity during normal hibernation period, 1906–7.*

DALLAS.

Date.	Weevils counted in section—										Total weevils counted.	Temperature.	
	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.		Max.	Mean.
1906.												°F.	°F.
Nov. 5	230	290	......	102	......	......	315	......	......	......	937	79	64.0
Nov. 10	62	96	......	......	......	......	......	......	......	......	158	86	67.5
Do	4	12	......	......	12	......	......	......	......	......	28	51	38.0
Nov. 28	......	......	130	1	33	......	4	7	......	......	175	62	54.0
Dec. 21	5	23	19	2	15	......	9	11	12	18	114	66	48.0
Dec. 27	8	10	48	5	20	......	8	7	19	25	150	73	64.0
1907.													
Jan. 1	9	18	39	7	28	......	13	11	43	80	248	75	69.5
Jan. 12	15	24	68	15	33	......	15	15	55	70	310	82	68.0
Jan. 24	4	5	25	3	17	21	4	......	16	14	109	73	48.5
Feb. 12	1	4	5	2	9	4	4	1	22	2	54	64	45.0
Feb. 19	3	4	7	3	21	7	14	5	50	9	123	80	65.0
Total	341	486	341	140	188	32	386	57	217	218	[a] 2,406	......	......

[a] This total represents 7.8 per cent of all the weevils put in the cage.

TABLE XXXI.—*Activity during normal hibernation period, 1906–7*—Continued.

CALVERT.

Date.	Weevils counted in section— 1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	Total weevils counted.	Temperature. Max.	Mean.
1906.												°F.	°F.
Nov. 17	17	......	......	28	233	......	28	161	......	......	467	......	......
Nov. 29	3	214	55	9	6	......	6	10	139	......	442	......	......
Dec. 22	4	47	30	4	8	217	0	17	69	1	397	60	48.0
1907.													
Jan. 14	11	68	41	12	10	90	3	12	50	2	299	82	70.0
Jan. 21	3	30	22	7	7	63	2	4	20	1	159	62	47.0
Jan. 28	1	13	7	1	3	37	1	5	17	1	86	56	39.0
Feb. 11	3	12	5	0	1	28	1	4	21	0	75	75	52.0
Feb. 18	1	13	6	0	2	43	2	2	22	0	91	79	62.0
Feb. 25	3	10	5	0	2	36	1	1	11	0	69	74	65.0
Total	46	407	171	61	272	514	44	216	319	5	[a]2,085	......	......

VICTORIA.

Date.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	Total weevils counted.	Max.	Mean.
1906.													
Nov. 25	133	204	......	159	......	......	......	......	......	......	496	74	66.5
Dec. 10	......	......	345	......	504	......	64	546	323	......	1,782	73	59.5
Dec. 19	......	......	163	......	......	......	......	......	236	19	418	47	40.0
Dec. 21	62	95	......	66	186	81	18	200	......	......	708	65	51.5
1907.													
Jan. 7	......	......	108	......	......	......	......	......	134	11	253	77	73.0
Jan. 14	147	89	......	62	......	106	......	......	......	......	404	77	72.0
Jan. 21	68	50	123	27	69	76	16	106	189	5	729	66	52.5
Feb. 4	48	55	89	40	85	46	43	67	123	3	599	60	50.0
Feb. 18	55	40	91	21	65	46	18	29	74	3	442	74	62.0
Feb. 26	49	28	75	13	66	31	50	......	......	......	312	70	66.5
Total	562	561	994	388	975	386	209	948	1,079	41	[b]6,143	......	......

[a] This total represents 10.5 per cent of all the weevils put in the cage.
[b] This total represents 27.7 per cent of all weevils put in the cage.

It is hardly probable that a majority of the weevils may have been counted upon two or more dates, but the fact that dead weevils were found clinging to the wire (Pl. VII, fig. 1) at the time of each examination indicates a considerable mortality among the active weevils and that the places of the dead ones in successive counts were taken by weevils which had become active since the preceding examination. The percentages of active weevils for the three localities show a rather significant difference, and are given for the sake of this comparison without presuming to state correctly the actual percentage of weevils placed in hibernation which remained active during the winter in the respective localities. At Dallas the 2,406 weevils counted during the winter constitute 7.8 per cent of the total number placed in hibernation. At Calvert the 2,085 active weevils constitute 10.5 per cent of the 19,408 placed in the cage. At Victoria the 6,143 active weevils constitute 27.7 per cent of the 22,463 in the experiment. Since approximately the same number of examinations were made in each locality the differences in percentage indicate in a general way the relative activity in these sections of the State. Thus at Dallas 8, at Calvert 11, and at Victoria 28 out of every 100 weevils placed in hibernation might have been active during the winter. Of course, it is likely that many weevils were counted twice. On the other hand, to counterbalance this duplication in the number recorded, it should be stated that undoubtedly many weevils were active at intervals between the counts which were either upon the ground or had returned to the ground before the examinations were made. Only those weevils which were found crawling upon the wire covering of the cage were recorded. The temperature conditions as shown for the dates of examination indicate that there would be no physiological difference in normal weevil activity upon those dates. The sectional totals indicate that variations in the class of shelter in the different sections exerted little, if any, effect upon the activity of weevils during the winter, with the exception that Spanish moss seemed to keep more weevils from becoming active than did any other shelter.

WINTER ACTIVITY.

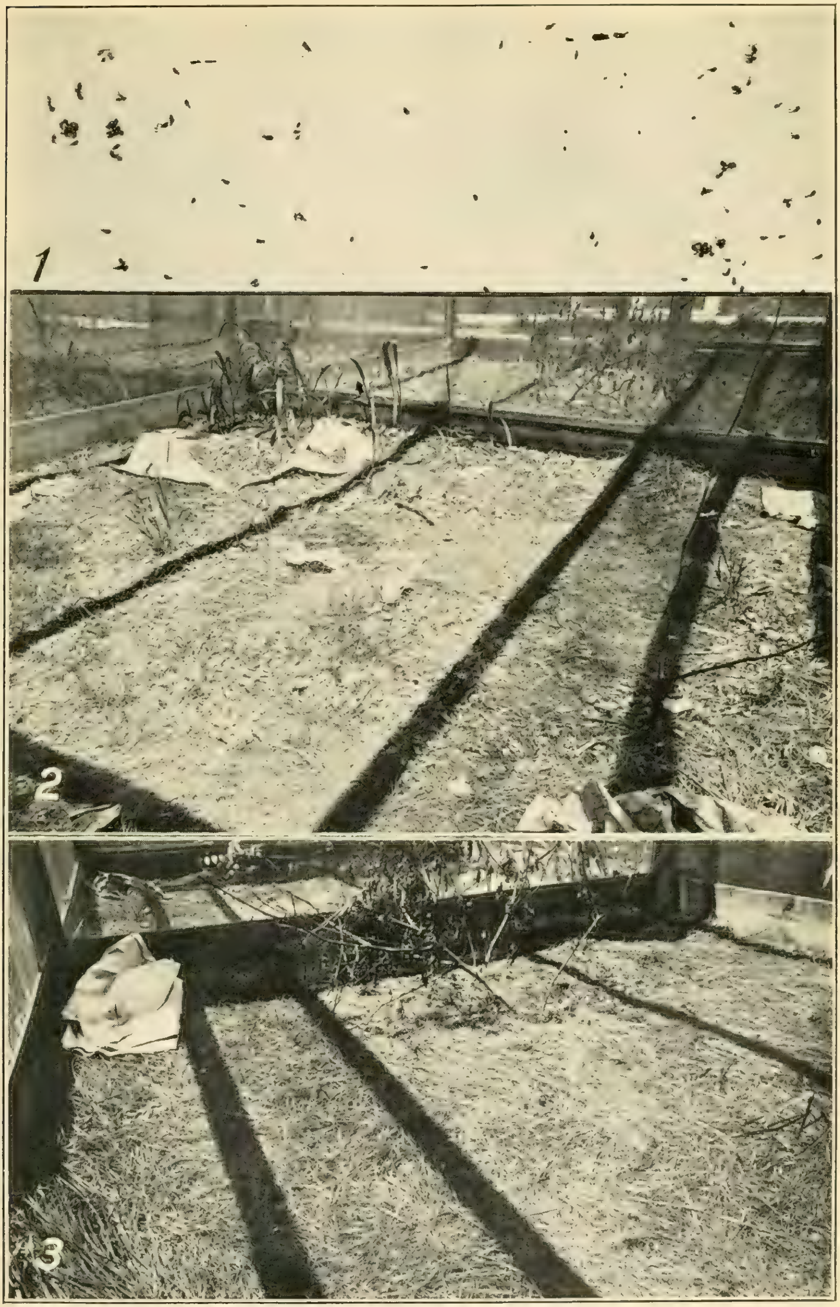
In most instances when the active living weevils were recorded those which were found dead clinging to the wire were collected and counted for each section. Undoubtedly a great many weevils fell from the screen before or after dying, so that the records are very conservative in showing the mortality occurring between examinations. These records should be considered in connection with weevil activity, since the collection of dead stages prevented their accumulation upon the wire, and the number found at each examination must be considered of those surviving and remaining on the wire from a preceding examination and those which emerged subsequently thereto.

TABLE XXXII.—*Summary of winter activity as shown by counts of dead weevils.*

DALLAS.

Date.	Number of dead weevils found in section—										Total number of dead weevils.
	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	
1907.											
January 5	2	3	4	1	34	......	10	7	10	4	75
January 12	0	1	......	......	2	......	......	......	......	......	3
January 24	2	2	2	......	2	[a] 672	......	......	2	5	[a] 687
February 12	1	3	4	1	5	7	3	1	6	7	38
February 19	......	......	3	1	3	1	1	......	3	1	13
Total	5	9	13	3	46	680	14	8	21	17	[b] 816

[a] Of these, 622 were on cloth on ground, having fallen from the wire.
[b] This total represents 2.6 per cent of all the weevils put in the cage.



SHELTER CONDITIONS, DALLAS, TEX., CAGE.

Fig. 1.—Active weevils trying to escape through wire on October 20, 1906. Fig. 2.—Section 1, in which weevils were placed October 13, 1906, 2.61 per cent surviving. Fig. 3.—Section 4, started October 16, 1906, 4.07 per cent surviving. (Original.)

TABLE XXXII.—*Summary of winter activity as shown by counts of dead weevils*—Con.

CALVERT.

Date.	Number of dead weevils found in section—										Total number of dead weevils.
	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	
1906.											
November 17	121	......	......	36	83	......	6	47	......	......	293
November 29	14	2	101	7	39	1	2	20	34	......	220
December 22	1	3	16	7	5	2	0	4	7	2	47
1907.											
January 14	5	4	3	2	5	10	0	3	10	1	43
January 21	0	......	12	......	5	12	0	0	6	0	35
January 28	1	......	......	0	......	......	0	0	......	0	1
February 11	0	5	5	2	0	12	0	3	3	0	30
February 18	1	4	3	0	0	4	0	2	9	0	23
February 25	0	......	1	0	0	0	1	0	......	0	2
Total	143	18	141	54	137	41	9	79	69	3	[a] 694

VICTORIA.

Date.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	Total.
1906.											
November 25	8	13	......	14	......	......	......	......	......	......	35
December 10	......	......	2	......	6	......	2	16	3	......	29
December 19	......	......	3	......	......	......	......	......	2	0	5
December 24	3	7	......	19	11	......	5	6	......	......	51
1907.											
January 7	......	......	0	......	......	......	......	......	0	0	0
January 14	3	4	......	5	......	2	......	......	......	......	14
January 21	6	10	12	6	12	4	2	12	5	2	71
February 4	9	8	9	2	10	1	2	14	11	1	67
February 18	6	2	7	8	4	1	0	12	11	0	51
February 26	9	11	4	5	11	5	0	......	......	......	45
Total	44	55	37	59	54	13	11	60	32	3	[b] 368

[a] This total represents 3.6 per cent of all the weevils put in the cage.
[b] This total represents 1.7 per cent of all the weevils put in the cage.

In the section of the table containing the records for Dallas the large number of weevils found dead in section 6 on January 24, 1907, may be explained by the statement that no previous collection of dead weevils had been made in this section. All but 50 of the weevils found were upon cheesecloth stretched horizontally across the section above the ground. The full number is included merely to indicate the proportion of weevils which probably fall to the ground upon dying. In this section less than 20 per cent remained upon the screen, and it is reasonable to suppose that a similar proportion may have existed in other sections. The percentage of mortality in each place is much smaller than the percentage of living weevils. Upon the charts shown in figures 3 to 5 the number of dead collected is indicated by a broken line extending beyond the line representing the number of living weevils.

ACTIVITY AS SHOWN BY DEVELOPMENT DURING NORMAL HIBERNATION PERIOD.

Under the heading "Stages entering hibernation" the principal data bearing upon developmental activity during the winter have been given. (See pp. 13 and 14.) Additional data have also been given in connection with "Shelter during hibernation." (See Table VII, p. 26; also Table IX, p. 28.) To these records for seasons preceding 1906–7 may be added the results of an experiment in collection of infested squares during this season. On November 23, 1906, Mr. J. D. Mitchell collected 100 fallen squares which were supposed to be infested. These were placed in the small cage under shelter and out of the reach of sunshine. On February 10, 1907, he found that 45 squares showed weevil emergence hulls, and the full number of adults was found; however, all were dead at that time. An examination of the remainder of the squares revealed but one dead larva. The others, apparently, had contained no weevil stages. Exceptionally warm weather had prevailed during December and January, as has been shown in figure 5. This had enabled the weevils to complete their development and emerge, but all had starved to death in the absence of any food supply.

Some very interesting facts are also brought out by a closer study of the records in connection with section 10 of each cage. As has been shown, the experiment in these sections consisted of the collection of large numbers of unopened bolls probably infested. Several of the bolls were buried under 2 inches of dirt and the remainder were exposed upon the surface of the ground (Pl. X, fig. 1). No partition was inserted to separate the weevils emerging from these two lots of bolls, but in the case of section 10 at Dallas the first lot of bolls was buried and a considerable period elapsed before the balance of the bolls, which were left upon the surface, was placed in the cage. It was estimated that 3,000 bolls were buried at a uniform depth of 2 inches under cover of heavy black soil. An examination of 100 bolls showed 8 recently transformed but unemerged adults in the bolls and 8 adults which had emerged were hibernating within the protection afforded by the bolls. On this basis it appears that about 480 weevils were buried in this lot of 3,000 bolls, half of them being unemerged adults and half hibernating adults. No other material was placed within this section, so that all weevils which were subsequently found upon the screen must necessarily have found their way through the 2 inches of soil under which the bolls were buried. Counts made before the bolls to be placed on the surface were put into the cage showed that 65 weevils at least had escaped from the bolls to the screen forming the cage. This shows that fully 13.5 per cent of all the weevils buried, emerged and unemerged, had succeeded in escaping. Undoubtedly part of these had left their cells in the bolls after they were buried, as it is very likely that the burial of the bolls in moist soil may soften the hulls so as to enable the weevils to escape through them as readily as though they remained dry upon the surface of the ground.

ACTIVITY IN THE FIELD DURING NORMAL HIBERNATION PERIOD.

For a number of years it has been known that, in southern Texas especially, weevils may frequently be found moving actively in the field during the winter, but the observations made during the season of 1906–7 extended the range of such occasional activity even in northern Texas.

TABLE XXXIII.—*Outdoor activity of weevils during winter of 1906–7.*

Locality.	Date.	Weevils found.	Sprout plants examined.	Remarks.
	1907.			
Dallas, Tex	Jan. 1	1		Found on awning rope.
Do	Jan. 11	1		Found on window screen; temperature 74° F.
Do	Feb. 12	1		Found on outside of hibernating cage; temperature 75° F.
College Station, Tex	Feb. 22	1		Do.
Do	Jan. 17	2		Feeding on sprout cotton.
	1906.			
Victoria, Tex	Dec. 29	9		When given sprouts, all were feeding in 80 minutes; temperature 82° F.
Do	do	10		When given sprouts, all were feeding in 45 minutes; temperature 82° F.
	1907.			
Do	Jan. 8	9	(a)	Mean temperature, January 1-8,=67.76° F.
Do	Jan. 9	20	(b)	On black land.
Do	Jan. 12	7	6	
Do	Jan. 16	1	50	10 weevils in bolls on the same plant.
Do	do	2	30	
Do	Jan. 17	4	8	
Do	Jan. 18	1	17	
Do	Feb. 14	1	25	Upland sprouts not killed as in bottoms.
Do	Feb. 21	3	50	Very dry for sprout growth.

[a] Record not kept, though plants were examined.
[b] Sprout cotton on six farms examined.

From the Victoria records it appears that between January 8 and February 21, at a time when weevils should normally have been in complete hibernation, 48 adults were found feeding on about 200 sprout plants. This record is unique for the United States, and a similar activity in the field may not be duplicated except under very rare conditions.

EMERGENCE FROM HIBERNATION, 1907.

As is plainly shown by figures 3 to 5, the actual period of general emergence from hibernation began in each locality about February 20. As has been previously stated, the actual date of the beginning of emergence can not be positively given. It can be better expressed as a period of "beginning emergence," and for this reason this period seems to lie between February 20 and March 1. Owing to the exceptional earliness of the season preparations for the regular observations upon emergence from hibernation were not sufficiently complete for beginning the work until March 1 and in each locality this date may very reasonably be considered as the beginning of the emergence period.

Previous experience having demonstrated the necessity of keeping the records upon this work according to a uniform system in each locality, the preparations were much more elaborately made than for any previous work. Comprehensive forms upon which the records might be entered with a minimum of labor were prepared covering five distinct divisions of the work: (1) Meteorological record; this record covered maximum and minimum temperatures, atmospheric humidity, rainfall, sunshine or cloudiness, and winter conditions. (2) Emergence record; this record showed the emergence in each section for each date. The records for one week were placed upon a card so that the totals for emergence for each day, and also for each section for each week, could be very readily ascertained. (3) Section record; this covered in more detail the emergence in each section and indicated the sex of emerging weevils and what disposition was made of them, in such a way that their records could be followed until the time of death. (4) Longevity records for fed weevils. (5) Longevity records for unfed weevils.

This systematization of the record work has proved an invaluable help in compiling the results of this extensive series of observations. The general facts regarding the relationship existing between climatic conditions and weevil emergence are indicated graphically in figures 6 to 8. The most important conclusions upon special points can only be shown by special arrangements of the data in each case. These tables have been made as concise as seems possible. Practically each line in the tables expresses only the summary of a large number of compiled records. The magnitude of the work involved in the completion of such data can be appreciated only by one who has undertaken a similar task.[a]

RELATIONSHIP OF EMERGENCE FROM HIBERNATION TO CLIMATIC CONDITIONS.

Figures 6 to 8 have been prepared in the same form as figures 3 to 5, since they express a continuation of similar facts.

In former reports,[b] dealing especially with the life history of the boll weevil, it was stated that emergence began about the time when the mean temperature rose above 60° F. The more complete

[a] The senior author desires to express particular appreciation of the great amount of detail work which has been done by the junior author (Mr. W. W. Yothers) in the preparation of the summaries covering this work.

[b] U. S. Dept. Agr., Bur. Ent., Buls. 45 and 51.

records now at hand indicate that emergence may take place whenever the mean average temperature exceeds 55° F. It is certain that weevils may be active at a temperature considerably lower than this, but the records do not indicate that there is a general

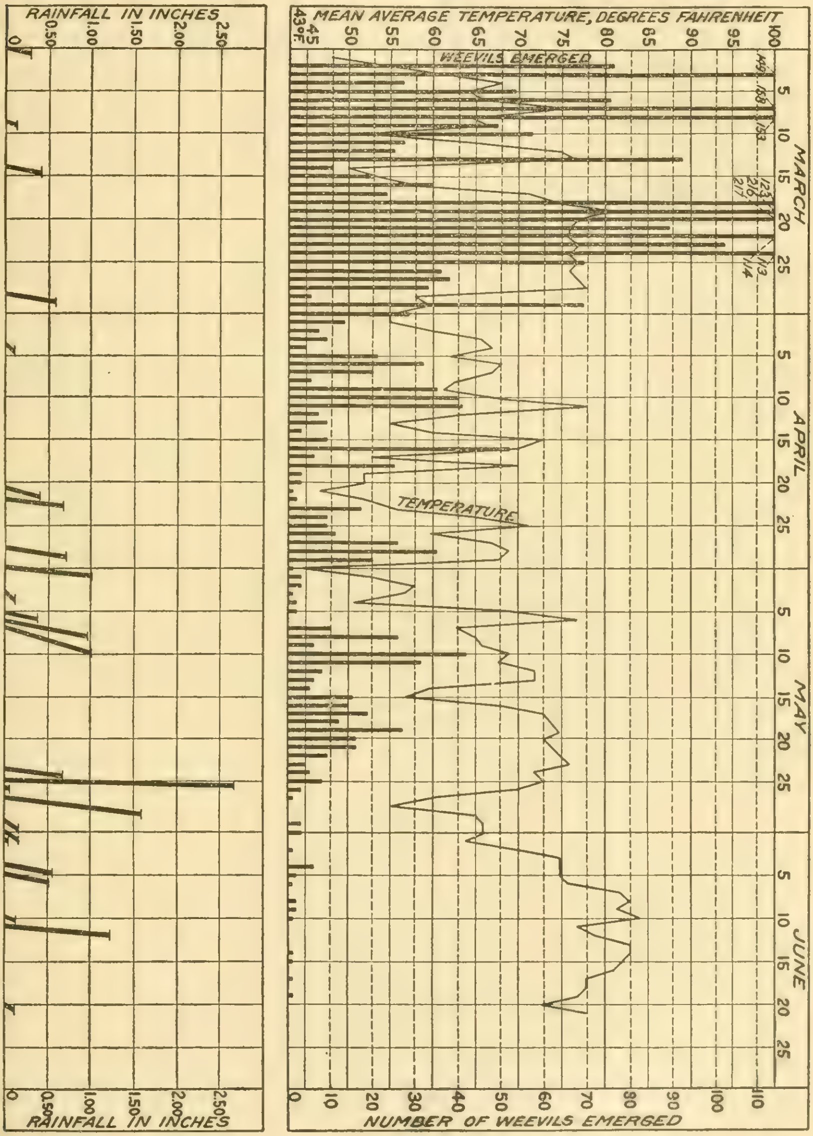


Fig. 6.—Chart showing mean average temperature, rainfall, and emergence from hibernation, Dallas, Tex., March to June, 1907.

emergence from hibernation at a lower temperature. After having left their winter quarters, weevils may continue active at considerably lower temperatures than are required to draw them out from their shelter. This statement may, in part at least, explain the continued activity of weevils during the winter of 1906–7 and the early beginning for the period of emergence for that season.

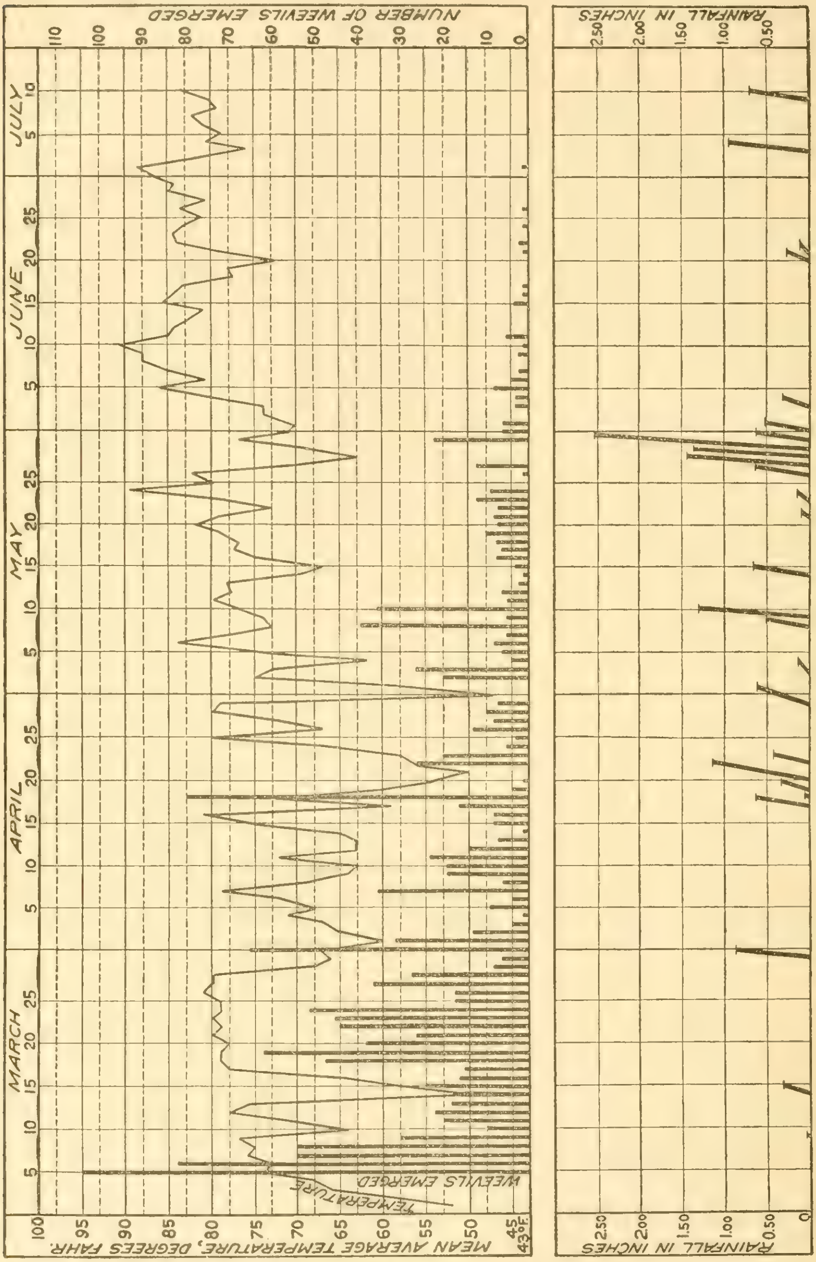


FIG. 7.—Chart showing mean average temperature, rainfall, and weevil emergence, Calvert, Tex., March to June, 1907.

A comparison of figures 6, 7, and 8 indicates that the period of greatest emergence in each locality occurred during March, 1907. The abnormal nature of temperature conditions is shown by the fact that at Dallas the mean average temperature for the month was over 11 degrees above the normal. At Calvert the departure was about the

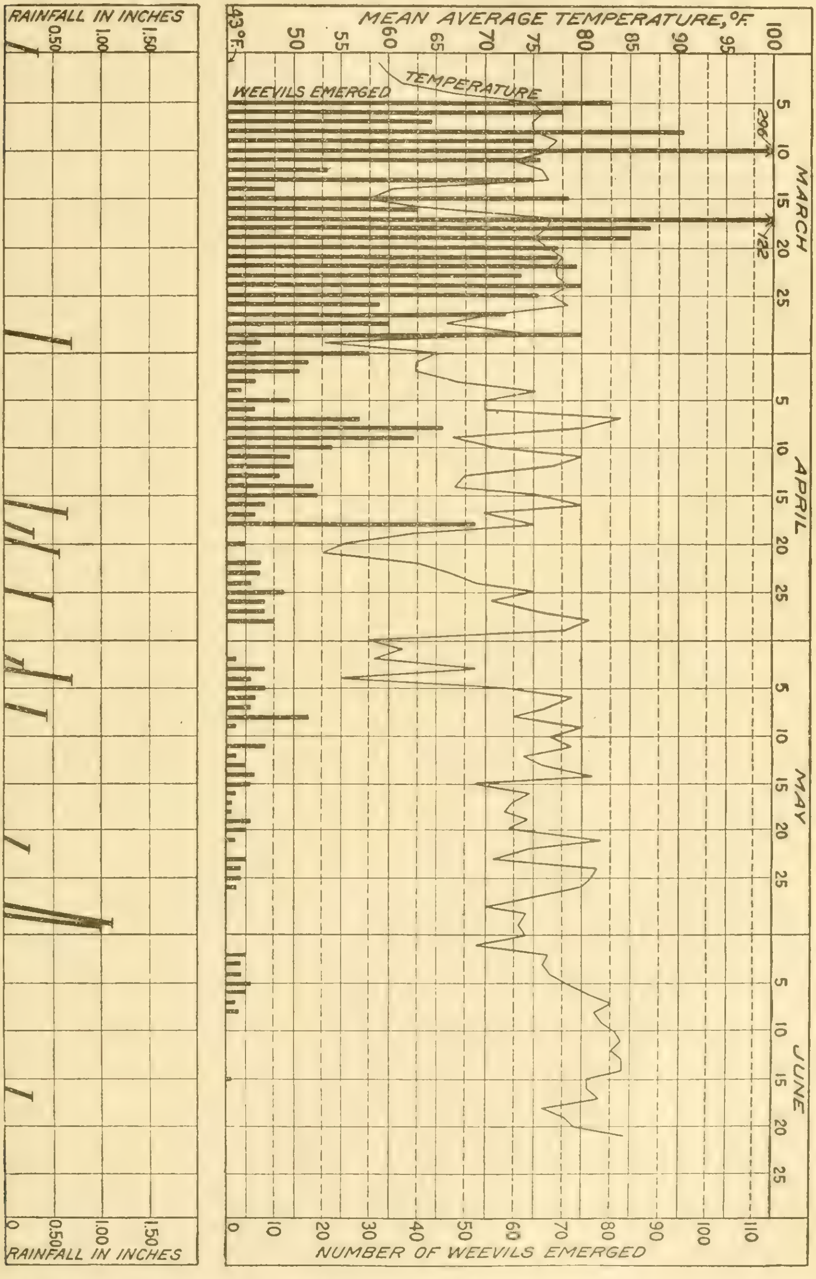


Fig. 8.—Chart showing mean average temperature, rainfall, and weevil emergence, Victoria, Tex., March to June, 1907.

same, and at Victoria it was but slightly less than 10 degrees above normal. Such high temperatures do not often occur before the latter part of April and the 1st of May. The temperature for April was unusually unfavorable, but in all sections it ranged from 3 to 5 degrees below the normal. This decrease was not, however, sufficient to check the emergence of weevils, although undoubtedly it served to extend the period of emergence in an unusual degree. The abnormal nature of the temperature conditions for the spring of 1907 may be understood from a comparison of the mean monthly temperatures for these four months in each case. The normal is determined by the Weather Bureau records from an average of the mean monthly temperatures for the entire period during which records are available. The departure of each season, therefore, affects the normal for the following season.

The general impression in regard to the exceptionally high temperature experienced during the winter of 1906–7 is confirmed by a comparison with the average records for a number of seasons. Temperature alone need be considered in making this comparison, although rainfall has an important direct effect upon temperature conditions. For the following comparison the records given by the United States Weather Bureau are used. As there is no report for Calvert the average of two points about equally distant on opposite sides of that place is used.

TABLE XXXIV.—*Mean monthly temperatures and departures from normal at Dallas, Calvert, and Victoria, Tex., November, 1906, to February, 1907.*

Locality.	November.		December.		January.		February.	
	Monthly mean.	Departure.	Monthly mean.	Departure.	Monthly mean.	Departure.	Monthly mean.	Departure.
	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
Dallas	54.3	−0.6	51.6	+3.8	53.4	+8.5	51.2	+6.6
Calvert	59.1	+ .1	56.8	+4.1	59.8	+9.6	54.8	+2.8
Victoria	62.9	−1.8	59.2	+1.4	63.4	+9.8	60.2	+6.2

It will be noted that the departure from normal during November was very slight. The temperature conditions, therefore, during the usual period of entrance into hibernation were practically normal, the rise occurring during December and January, especially when weevils should normally have been in complete hibernation. Table XXXV continues the same study throughout the period of emergence from hibernation.

TABLE XXXV.—*Mean average temperatures and departures from normal at Dallas, Calvert, and Victoria, Tex., March to June, 1907.*

Locality.	March.		April.		May.		June.	
	Monthly mean.	Departure.	Monthly mean.	Departure.	Monthly mean.	Departure.	Monthly mean.	Departure.
	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
Dallas	66.7	+11.1	61.4	−4.2	65.8	−7.7	78.8	−1.9
Calvert	70.0	+ 9.2	62.2	−5.9	66.6	−7.3	76.6	−4.4
Victoria	72.4	+ 9.7	69.4	−3.3	73.0	−5.0	81.6	− .6

The unprecedented emergence during March is very easily explained by the remarkable temperature conditions during that month. In spite of the fact that emergence began earlier than had ever been known previously, it continued later also because of the exceptionally low temperatures prevailing during April, May, and June. A comparison of figures 1 and 2 with figures 6 to 8 is interesting and shows how strikingly the nature of the emergence movement may vary in respect to difference in climatic conditions. The careful examinations made to discover the termination of the emergence period were continued for fully two weeks after the last weevil was found. It seems impossible to explain the long-delayed emergence of some individuals. The lack of an explanation, however, does not alter the fact that emergence is probably not generally complete until after the middle of June.

TABLE XXXVI.—*General summary of experiments of 1906–7 on emergence from hibernation.*

Locality.	Number of weevils—		Number of weevils emerging	Percentage emerging.
	Put in cages.	Used as basis for percentage of emergence.[a]		
Dallas, Tex.	32,439	30,864	3,464	11.22
Calvert, Tex.	20,430	19,408	1,842	9.49
Victoria, Tex.	23,645	22,463	[b] 3,026	13.47
Total and average	76,514	72,735	8,332	11.45

[a] Basis for computing the percentage of emergence is 5 per cent less than the number of weevils put in cages owing to the escape of some weevils through the meshes of the wire.
[b] Two weevils not in summary.

A deduction of 5 per cent from the number of weevils placed in the hibernation experiments is made to furnish a more correct basis for determining percentages, on account of the fact that experiments have shown that about 5 per cent of a miscellaneous collection of weevils may be able to escape through 14-mesh wire (Pl. VII, fig. 1), such as was used in the construction of these cages. The percentage of survival is strikingly similar in each locality. The average surviving hibernation—approximately 11 per cent—is probably the highest that has ever occurred since the weevil entered Texas. Although observations have indicated that occasionally the percentage of survival may be as high as this in the field, it is fortunate for the cotton planter that such is very rarely the case.

EFFECT OF TIME OF ENTERING HIBERNATION AND NATURE OF SHELTER UPON THE PERCENTAGE OF SURVIVAL.

One of the most important points upon which information was sought throughout these experiments was the effect of time of entering hibernation and nature of shelter upon the percentage of survival. The first confinement of weevils in the fall occurred fully a month earlier than the beginning of similar experiments the previous year, and it was expected that the intervals between their confinement in the cage and the time for successful hibernation might be sufficient to plainly reduce the proportion of weevils surviving.

TABLE XXXVII.—*Chronological arrangement of sectional records showing relative survival at Dallas, Calvert, and Victoria, Tex., 1906-7.*

DALLAS.

When started.	Section number.	Character of shelter and food.	Date of last emergence.	Basis number of weevils.	Total weevils emerged.	Percentage of survival.	Rank of section in survival.
1906.			1907.				
Oct. 13	1	Leaves and hay, 4 inches deep, cotton stalks left[a]	May 21	3,800	99	2.61	12
Oct. 16	4	Leaves and hay; stalks cut and left four days[b]	May 6	2,090	85	4.07	11
Oct. 20	2	Leaves and grass 4-5 inches deep; no food	May 19	3,610	226	6.26	7
Oct. 24	7	Spanish moss and chips;[c] cut food	June 17	3,325	231	6.95	6
Oct. 30	8	Leaves and grass 2-3 inches deep; no food[d]	June 15	2,850	250	8.85	5
Nov. 5	5	Leaves and grass 9-10 inches deep; stalks cut and left[e]	May 15	3,135	383	12.22	4
Nov. 12	3	Leaves and grass; no food[f]	May 21	3,040	448	14.74	3
Nov. 13	9	Leaves 8-10 inches deep; green cotton cut and left[g]	June 19	3,040	788	25.92	2
Nov. 15	11	Leaves 3-4 inches deep; stalks left standing	June 4	2,565	804	31.34	1
Nov. 21	12	.....do	June 8	1,570	65	[h] 4.14	10
Nov. 28	6	Bare ground; no food	Apr. 29	975	46	4.72	8
Dec. 6	10	{Bolls[i] on surface[j] / Bolls[i] buried[j]}	May 2	864	39	4.51	9
		Total and average		30,864	3,464	11.22	

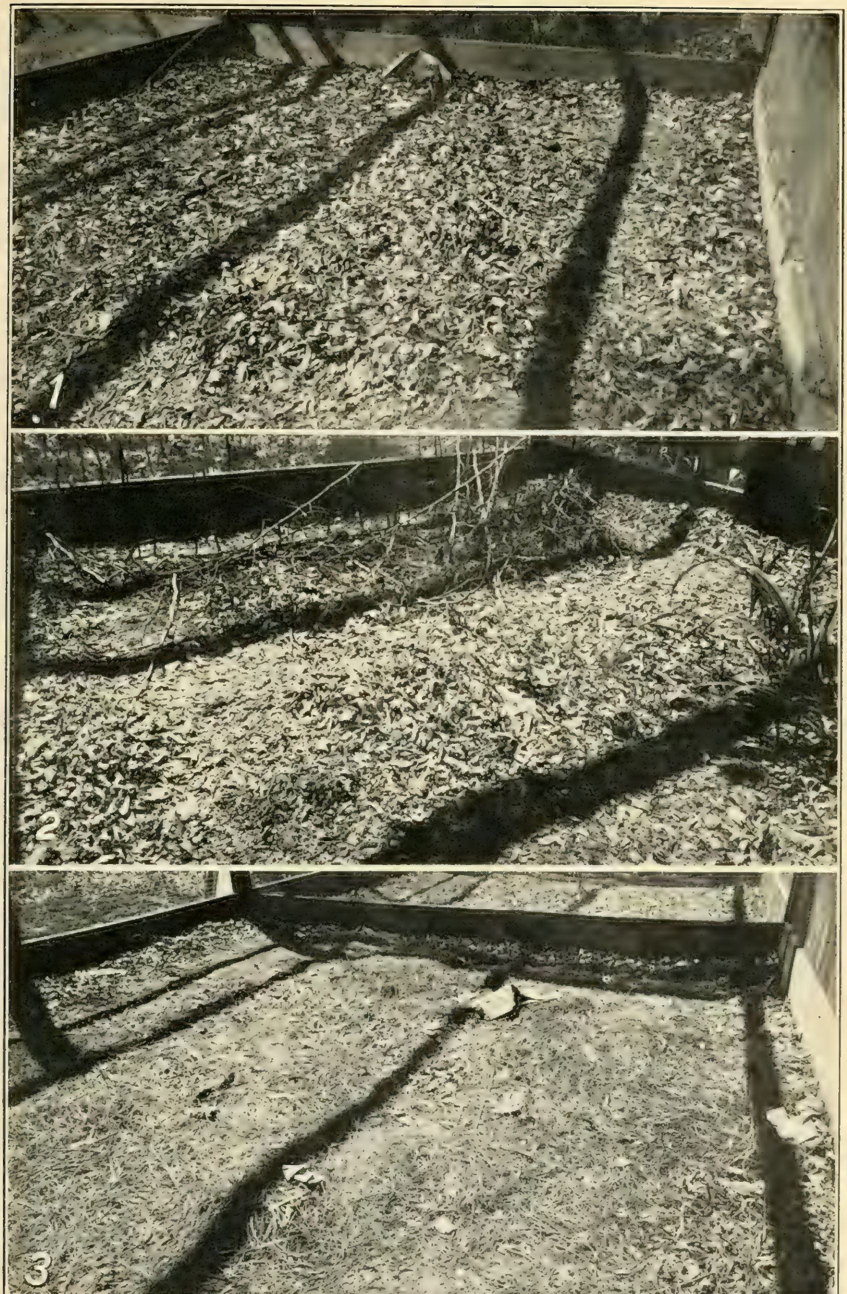
CALVERT.

When started.	Section number.	Character of shelter and food.	Date of last emergence.	Basis number of weevils.	Total weevils emerged.	Percentage of survival.	Rank of section in survival.
Oct. 13	1	Food, two days; grass and leaves 4-5 inches deep	June 12	2,375	75	3.15	7
Oct. 19	4	Grass and leaves 4-5 inches deep	May 30	2,375	116	4.88	5
Oct. 25	7	Spanish moss; chips	July 1	2,375	105	4.42	6
Oct. 31	8	Food two days; grass and leaves 4-5 inches deep	May 30	2,375	63	2.65	8
Nov. 5	5	Food dry; grass and leaves 4-5 inches deep	Apr. 26	2,375	45	1.89	9
Nov. 12	9	Food cut down, left dry; 10 inches grass and leaves	June 12	2,375	438	18.44	3
Nov. 14	3	Stalks cut down, left dry; 2 inches grass and leaves	May 31	2,375	253	10.65	4
Nov. 25	6	Field protection or bare; some grass	May 16	1,425	359	25.19	2
Nov. 26	2	No food; leaves and hay	June 12	1,358	380	27.98	1
Dec. 3	10	Bolls	Mar. 24	([k])	8	....	10
		Total and average		19,408	1,842	9.49	

[a] See Pl. VII, fig. 2.
[b] See Pl. VII, fig. 3.
[c] See Pl. VIII, figs. 1, 2.
[d] See Pl. IX, fig. 1.
[e] See Pl. IX, fig. 2.
[f] See Pl. IX, fig. 3.
[g] See Pl. X, fig. 2.
[h] The weevils put in on November 21 were brought from Brownsville, Tex. The low percentage of survival doubtless resulted from their weakened condition, owing to insufficient food during transportation.
[i] Bolls presumably infested.
[j] See Pl. X, fig. 1.
[k] No estimate made.

HANGING MOSS AS AFFECTING HIBERNATION AND EMERGENCE.

Fig. 1.—Section 7, with hanging moss in top of cage. Fig. 2.—Same section, ground conditions, started October 24, 1906; 6.95 per cent surviving; emergence ceased June 17, 1907. (Original.)



SHELTER CONDITIONS PRODUCING AVERAGE SURVIVAL AT DALLAS, TEX.

Fig. 1.—Section 8, started October 30, 1906; emergence ceased June 15, 1907; survival, 8.85 per cent. Fig. 2.—Section 5, started November 5, 1906; emergence ceased May 15, 1907; survival, 12.22 per cent. Fig. 3.—Section 3, started November 12, 1906; emergence ceased May 21, 1907; survival, 14.74 per cent. (Original.)

EXCEPTIONALLY FAVORABLE CONDITIONS AND BOLL EXPERIMENT.

Fig. 1.—Section 10, *a*, bolls exposed on surface; *b*, corner where bolls were buried 2 inches deep, started December 6, 1906; emergence ceased May 2, 1907; survival, 4.51 per cent. Fig. 2.—Section 9, stalks left, started November 13, 1906; emergence ceased June 19, 1907; survival, 25.92 per cent. (Original.)

TABLE XXXVII.—*Chronological arrangement of sectional records showing relative survival at Dallas, Calvert, and Victoria, Tex., 1906-7*—Continued.

VICTORIA.

When started.	Section number.	Character of shelter and food.	Date of last emergence.	Basis number of weevils.	Total weevils emerged.	Percentage of survival.	Rank of section in survival.
1906.			1907.				
Oct. 25	1	Weeds and grass 5 inches; stalks left.	May 11	2,375	201	8.46	7
Do....	4	Weeds and grass 5 inches; stalks removed	May 15	2,375	105	4.42	9
Oct. 28	2	Weeds and grass 4-5 inches; stalks cut, left	May 11	2,375	134	5.61	8
Nov. 6	7	Moss, bark, chips, etc.; no food	June 15	2,850	674	23.65	1
Nov. 10	8	Grass and weeds 5 inches; stalks removed	May 6	2,850	362	12.70	6
Nov. 14	5	Stalks pulled, left; grass and weeds 5 inches	Apr. 28	2,850	449	15.86	3
Nov. 21	9	Grass and weeds 10 inches; stalks pulled and left	May 23	2,850	374	13.19	4
Do....	3	Weeds and grass 2 inches; stalks pulled and left	...do	2,850	588	20.63	2
Nov. 28	6	Ground bare; no food	May 11	1,088	139	12.78	5
Nov. 29	10	Bolls [a]	Mar. 4	(a)	2	....	10
		Total and average	....	22,463	3,028	13.47	....

[a] Three bushels of bolls on the surface, and 3 bushels covered with 2 inches of earth.

The results of this work are exceptionally striking in the case of the Dallas record. The Calvert record ranges between that of Dallas and Victoria in regard to the clearness with which comparative effects are shown. In each case there is, however, a general tendency toward more successful hibernation as the season advances after the middle of October until the time when frosts occur. In the case of the Dallas records there occurred an almost uninterrupted increase in percentage of survival with each date upon which experiments were started. The apparent exceptions are readily explainable by other facts than the time of starting the experiment. Section 12, which ranged sixth, received weevils collected at Brownsville, Tex., which made it necessary to ship for a long distance. During this shipment their food supply became poor, and the weevils were undoubtedly much weaker upon being placed in the cage than were those which had been collected in the immediate vicinity of Dallas. Section 6 was not provided with any shelter for the weevils, and the percentage of survival was smaller on that account than in other sections started at about the same date. Section 10, which ranged ninth, received only infested bolls, upon and within which weevils were hibernating. From October 13 to November 15, under approximately similar conditions, the percentage of survival increased from 2.61 to 31.34. (See Pl. VII, figs. 2, 3.) A more forceful argument than this for the destruction of the food supply as early in the fall as is possible could hardly be given.

A combination of the records for those localities at which experiments were started upon the same or approximate dates, grouping them so that the chronological sequence is most clearly shown, adds additional emphasis to the statements which have just been made.

TABLE XXXVIII.—*Comparison of sectional records grouped by approximate initial dates.*

Date.	Locality.	Section number.	Basis number of weevils.	Total number emerged.	Percentage of survival.	Rank in percentage of survival.
1906.						
Oct. 13	Dallas	1	3,800	99	2.61	
Do	Calvert	1	2,375	75	3.15	8
Oct. 16	Dallas	4	2,090	85	4.07	
	Total and average		8,265	259	3.13	
Oct. 19	Calvert	4	2,375	116	4.88	7
Oct. 20	Dallas	2	3,610	226	6.26	
	Total and average		5,985	342	5.71	
Oct. 24	Dallas	7	3,325	231	6.95	
Oct. 25	Calvert	7	2,375	105	4.42	5
Do	Victoria	1	2,375	201	8.46	
Do	do	4	2,375	105	4.42	
	Total and average		10,450	642	6.15	
Oct. 28	Victoria	2	2,389	134	5.61	
Oct. 30	Dallas	8	2,850	250	8.85	6
Oct. 31	Calvert	8	2,375	63	2.65	
	Total and average		7,614	447	5.87	
Nov. 5	Dallas	5	3,135	383	12.22	
Do	Calvert	5	2,375	45	1.89	4
Nov. 6	Victoria	7	2,850	674	23.65	
	Total and average		8,360	1,102	13.18	
Nov. 10	Victoria	8	2,850	362	12.70	
Nov. 12	Dallas	3	3,040	448	14.74	
Nov. 14	Calvert	9	2,375	438	18.44	2
Nov. 13	Dallas	9	3,040	788	25.92	
Nov. 14	Victoria	5	2,850	449	15.86	
Nov. 15	Dallas	11	2,565	804	31.34	
	Total and average		16,720	3,289	19.67	
Nov. 21	Dallas	12	1,570	65	[a] 4.14	
Do	Victoria	9	2,836	374	13.19	3
Do	do	3	2,850	588	20.63	
	Total and average		7,256	1,027	[b] 14.15	
Nov. 25	Calvert	6	1,425	359	25.19	
Nov. 26	do	2	1,358	380	27.98	1
Nov. 28	Dallas	6	975	46	[c] 4.72	
Do	Victoria	6	1,088	139	[c] 12.78	
	Total and average		4,846	924	[d] 19.07	

[a] Brownsville, Tex., weevils.
[b] Average omitting Brownsville weevils, 16.91 per cent.
[c] Absolutely bare ground.
[d] Average without Dallas cage, 22.7 per cent.

In this table it may be seen that, taking all localities together, whenever experiments were started upon approximately the same date there is a most striking increase in successful survival at intervals between the middle of October and the middle of November. This table may be safely considered as representing in the most general way possible the facts in regard to this point. An interval of about eleven days between October 14 and 25 practically doubled the percentage of weevils surviving. Again, in an interval of about ten days between October 25 and November 5 the percentage was again doubled, and an increase of 50 per cent was observable between November 5 and 14. After November 14 hibernation might have been successful for practically the maximum possible proportion of weevils. The relation of these figures may be most simply expressed in the following manner: Under similar conditions of shelter, but without a food supply, if the survival of weevils in Texas for October 15 is one, for October 25 it will be two; for November 5, four; and for November 15, six. These figures make it evident that from October 15 to November 15 constitutes the strategic period for attack upon the boll weevil. The attack can be made in two ways: (1) By the destruction or removal of the conditions favorable for the shelter of the weevil through the winter; (2) by the destruction of the food supply. These conclusions have frequently been stated and are here repeated because the facts here presented prove more conclusively than have any other data heretofore obtained the unquestionable importance of fall work in combating the boll weevil. The benefit, obviously, will always be realized during the following season by a much smaller injury to the crop. Considerations, both of minimum expense and of maximum effectiveness, emphasize this conclusion.

SURVIVAL OF WEEVILS BY LOCALITIES AND CAGE SECTIONS.

In practically all of the sections it may be considered that the emergence period began during the last few days of February and the first few days of March, March 1 being, approximately, the average date in each case. In the following table the summaries of the sectional records in each locality are given, together with the data necessary to show the maximum length of the hibernation period and the percentage of survival in each section:

TABLE XXXIX.—*Maximum hibernation period and percentage of survival by sections, 1906.*

DALLAS.

Section number.	When installed.	Weevils started.	Number used as basis of percentage.	Date of last emergence.	Total weevils emerged.	Percentage of survival.
	1906.			1907.		
1	Oct. 13	4,000	3,800	May 21	99	2.61
2	Oct. 20	3,800	3,610	May 19	226	6.26
3	Nov. 12	3,200	3,040	May 21	448	14.74
4	Oct. 16	2,200	2,090	May 6	85	4.07
5	Nov. 5	3,300	3,135	May 15	383	12.22
6	Nov. 28	1,025	975	Apr. 29	46	4.72
7	Oct. 24	3,500	3,325	June 17	231	6.95
8	Oct. 30	3,000	2,850	June 15	250	8.85
9	Nov. 13	3,200	3,040	June 19	788	25.92
10	Dec. 6	864	864	May 2	39	4.51
11	Nov. 15	2,700	2,565	June 4	804	31.34
12	Nov. 21	1,650	1,570	June 8	65	4.14
Total and average		32,439	30,864		3,464	11.22

TABLE XXXIX.—*Maximum hibernation period and percentage of survival by sections, 1906*—Continued.

CALVERT.

Section number.	When installed.	Weevils started.	Number used as basis of percentage.	Date of last emergence.	Total weevils emerged.	Percentage of survival.
	1906.			1907.		
1	Oct. 13	2,500	2,375	June 12	75	3.15
2	Nov. 26	1,430	1,358	....do....	380	27.98
3	Nov. 14	2,500	2,375	May 31	253	10.65
4	Oct. 19	2,500	2,375	May 30	116	4.88
5	Nov. 5	2,500	2,375	Apr. 26	45	1.89
6	Nov. 25	1,500	1,425	May 16	359	25.19
7	Oct. 25	2,500	2,375	July 1	105	4.42
8	Oct. 31	2,500	2,375	May 30	63	2.65
9	Nov. 12	2,500	2,375	June 12	438	18.44
10	Dec. 3	Bolls.	(a)	Mar. 24	8	....
Total and average	....	20,430	19,408	....	1,842	9.49

VICTORIA.

Section number.	When installed.	Weevils started.	Number used as basis of percentage.	Date of last emergence.	Total weevils emerged.	Percentage of survival.
1	Oct. 25	2,500	2,375	May 11	201	8.46
2	Oct. 28	2,515	2,389	....do....	134	5.61
3	Nov. 21	3,000	2,850	May 23	588	20.63
4	Oct. 25	2,500	2,375	May 15	105	4.42
5	Nov. 14	3,000	2,850	Apr. 28	449	15.86
6	Nov. 28	1,145	1,088	May 11	139	12.78
7	Nov. 6	3,000	2,850	June 15	674	23.65
8	Nov. 10	3,000	2,850	May 6	362	12.70
9	Nov. 21	2,985	2,836	May 23	374	13.19
10	Nov. 29	(b)	(b)	Mar. 4	2	....
Total and average	....	23,645	22,463	....	3,028	13.47

a No estimate made. b Three bushels of bolls on surface and 3 bushels covered with earth.

The longest period of hibernation occurred at Calvert among the weevils placed in section 7 on October 25, the last weevil emerging from this section being taken on July 1, 1907. During this period of over eight months this weevil survived without a particle of food. This may be considered as representing the maximum hibernation period, and in the case of an insect producing numerous generations during each season it is surprising that the hibernation period can be so greatly prolonged.

The largest average percentage of survival occurred at Victoria, although the variation between the three localities was not unexpectedly great. The nature of the shelter provided in each section has been indicated upon page 57. A comparison of the records for section 7 for Calvert and Dallas with those for the same section at Victoria shows that at the last-named place the survival was four times as great as in the average of Dallas and Calvert. The shelter provided was as closely similar in the case of this section as in any of the series, and the significant point of difference appears, therefore, to be the time when weevils were inclosed. At Dallas and Calvert this occurred on October 24 and 25, respectively, while at Victoria weevils were not placed in the cage until November 6. Apparently, therefore, the much larger survival at Victoria was due primarily to the starting of the experiment about twelve days later than in the other two localities.

The significance of the time of beginning the experiments is well emphasized by the records for sections 2 and 6 at Calvert. These two sections furnished by far the highest percentages of survival at that place, and apparently the only fact explaining this is that the experiment was started in each case at the time which was most favorable for successful hibernation, i. e., about November 25. This date was ten or twelve days later than those for sections 3 and 9, which present the next higher percentages of survival. An average of these two sections shows that among the weevils starting hibernation about November 12, 14.5 per cent survived, while among those starting hibernation about November 25, about 26.5 per cent survived.

The records for Dallas show that the three highest percentages of survival occurred in sections 11, 9, and 3, which were started between November 12 and 15.

In each locality the average date for the termination of emergence occurred between May 22 and 29. It is evident, therefore, that during 1906 the period of emergence from hibernation covered practically three months for an average of all of the sections and slightly more than four months for the last emerged weevils.

MONTHLY SUMMARY OF EMERGENCE RECORDS.

While it is important to know, approximately at least, the maximum limit of the emergence period, it may seem more desirable to determine the time at which a majority of weevils surviving had emerged. It is more convenient in using the records to compare them in four-week periods rather than according to calendar months.

TABLE XL.—*Emergence in 1907, by four-week periods.*

Locality.	Mar. 1–28, weevils emerged.		Mar. 29–Apr. 25, weevils emerged.		Apr. 26–May 23, weevils emerged.		May 24–July 1, weevils emerged.		Total emergence.
	Number.	Per cent of total.	Number.	Per cent of total.	Number.	Per cent of total.	Number.	Per cent of total.	
Dallas	2,486	71.8	484	14.0	452	13.0	42	1.2	3,464
Calvert	1,053	57.1	410	22.3	284	15.4	95	5.2	1,842
Victoria	2,399	79.3	476	15.7	119	3.9	32	1.1	3,026
Total and average	5,938	71.3	1,370	16.4	855	10.3	169	2.0	8,332

WEEKLY EMERGENCE RECORDS.

The following table presents a summary of the daily emergence records for each section during seven-day periods from March 1 to the end of the hibernation period. These records are particularly interesting in showing the variation occurring in emergence in the same section and locality during the different periods.

TABLE XLI.—*Summary of emergence of weevils in cage sections by weekly periods, March 1 to June 20, 1907.*

DALLAS.

Weekly period.	Number of weevils emerged in section number—											
	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.
Mar. 1-7	40	69	155	36	151	21	73	79	212	12	......	......
Mar. 8-14	8	36	51	10	46	7	25	31	120	7	65	7
Mar. 15-21	17	39	85	11	89	11	64	35	202	13	145	10
Mar. 22-28	10	21	38	8	51	2	25	22	123	4	189	11
Mar. 29-Apr. 4	4	20	19	3	8	1	4	15	7	1	49	4
Apr. 5-11	7	13	30	7	10	3	7	10	17	1	78	11
Apr. 12-18	1	6	12	1	7	0	8	5	10	0	55	6
Apr. 19-25	1	5	8	0	1	0	2	3	6	0	15	0
Apr. 26-May 2	5	10	16	3	5	1	2	20	8	1	27	1
May 3-9	2	3	21	3	7	0	7	14	26	0	40	6
May 10-16	2	2	10	0	8	0	2	7	29	0	58	3
May 17-23	2	2	3	0	0	0	8	3	16	0	67	2
May 24-30	0	0	0	0	0	0	0	3	4	0	12	1
May 31-June 6	0	0	0	0	0	0	1	2	4	0	4	2
June 7-13	0	0	0	0	0	0	1	0	3	0	0	1
June 14-20	......	......	......	......	......	......	2	1	1	......	......	......
Total	99	226	448	82	383	46	231	250	788	39	804	65

CALVERT.

Weekly period.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.
Mar. 4-7	25	99	54	23	15	136	9	7	49	3	......	......
Mar. 8-14	9	39	23	10	6	47	4	2	27	1	......	......
Mar. 15-21	9	54	37	12	9	45	2	3	55	2	......	......
Mar. 22-28	7	41	36	22	6	57	5	11	50	2	......	......
Mar. 29-Apr. 4	2	23	18	4	4	22	3	5	47	0	......	......
Apr. 5-11	0	14	9	7	3	21	6	11	44	0	......	......
Apr. 12-18	8	28	24	9	1	16	6	3	39	0	......	......
Apr. 19-25	2	6	2	1	0	6	1	2	13	0	......	......
Apr. 26-May 2	2	9	9	6	1	3	5	2	21	0	......	......
May 3-9	3	24	23	16	0	3	5	7	32	0	......	......
May 10-16	1	12	9	2	0	3	4	4	24	0	......	......
May 17-23	5	17	6	2	0	0	8	3	13	0	......	......
May 24-30	1	8	2	2	0	0	16	3	12	0	......	......
May 31-June 6	0	3	1	0	0	0	16	0	10	0	......	......
June 7-13	1	3	0	0	0	0	4	0	2	0	......	......
June 14-20	0	0	0	0	0	0	5	0	0	0	......	......
June 21-27	......	......	......	......	......	......	5	......	......	......	......	......
June 28-July 4	......	......	......	......	......	......	1	......	......	......	......	......
Total	75	380	253	116	45	359	105	63	438	8	......	......

VICTORIA.

Weekly period.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.
Feb. 28	39	24	69	13	60	35	29	31	63	......	......	......
Mar. 1-7	32	23	95	20	80	29	36	92	72	2	......	......
Mar. 8-14	54	36	130	22	103	24	63	107	76	0	......	......
Mar. 15-21	36	18	94	19	88	25	124	72	67	0	......	......
Mar. 22-28	18	10	54	13	58	18	170	26	30	0	......	......
Mar. 29-Apr. 4	9	6	51	9	17	5	19	15	16	0	......	......
Apr. 5-11	3	8	44	0	26	0	64	8	12	0	......	......
Apr. 12-18	5	5	28	5	7	0	47	5	25	0	......	......
Apr. 19-25	1	1	9	1	6	0	11	2	6	0	......	......
Apr. 26-May 2	1	0	4	1	4	0	14	1	1	0	......	......
May 3-9	2	2	8	0	0	0	31	3	4	0	......	......
May 10-16	1	1	1	2	0	1	20	0	0	0	......	......
May 17-23	0	0	1	0	0	0	14	0	2	0	......	......
May 24-30	0	0	0	0	0	0	8	0	0	0	......	......
May 31-June 6	0	0	0	0	0	0	21	0	0	0	......	......
June 7-13	0	0	0	0	0	0	2	0	0	0	......	......
June 14-20	......	......	......	......	......	......	1	......	......	......	......	......
Total	201	134	588	105	449	137	674	362	374	2	......	......

There is no indication that the time at which an experiment was begun affected essentially the nature of the emergence movement. The nature of the shelter, however, does seem to have an important influence. This is most clearly marked in section 7, where the experimental shelter was Spanish moss. At Victoria after about the 12th of April more weevils emerged from this section than from all others combined. This effect was less marked in the other localities, but in each case there appeared to be a considerable delay in emergence, due to the nature of this shelter. Owing to the fact that this moss is living and growing while hanging in the cages or on the trees, it takes up moisture as no other class of shelter does. The evaporation of this moisture during the daytime then serves to keep the mass of moss cool, and it is a well-known fact that the temperature in bunches of this moss is several degrees lower than that of the air during the daytime. Undoubtedly the lower temperature in the moss is the factor which retards the emergence of the weevils so decidedly. This factor may also be considered responsible for the smaller activity of weevils shown in the moss sections during the winter. (See Table XXXI, p. 63.)

A somewhat more detailed statement of the emergence shows more plainly the peculiar manner in which this was distributed during 1907. The figures are arranged for seven-day periods, and show the average temperature conditions prevailing as well as the percentage total of emergence occurring during each week.

TABLE XLII.—*Weekly summary of emergence records, showing relation to effective temperatures, 1907.*

Date.	Locality.	Mean average effective temperature.	Number of weevils emerged.	Percentage of total emergence.
1907.		°*F.*		
Mar. 1-7	Calvert	30.0	420	22.8
	Dallas	19.7	848	24.5
	Victoria	24.7	*a* 363	*a* 12.0
			481	15.9
Mar. 8-14	Calvert	25.7	168	9.1
	Dallas	21.0	413	11.9
	Victoria	30.5	609	20.3
Mar. 15-21	Calvert	30.5	228	12.4
	Dallas	27.0	721	20.8
	Victoria	29.0	549	18.0
Mar. 22-28	Calvert	36.6	237	12.9
	Dallas	33.0	504	14.6
	Victoria	32.5	397	13.1
Mar. 29-Apr. 4	Calvert	23.0	128	7.0
	Dallas	17.5	135	4.0
	Victoria	22.8	147	4.8
Apr. 5-11	Calvert	28.8	115	6.2
	Dallas	24.0	194	5.6
	Victoria	31.9	165	5.4
Apr. 12-18	Calvert	24.9	134	7.3
	Dallas	20.0	111	3.2
	Victoria	28.7	127	4.2
Apr. 19-25	Calvert	17.8	33	1.8
	Dallas	13.0	44	1.3
	Victoria	19.0	37	1.2
Apr. 26-May 2	Calvert	24.8	58	3.1
	Dallas	16.3	99	2.9
	Victoria	26.3	26	.86

a On February 28.

TABLE XLII.—*Weekly summary of emergence records, showing relation to effective temperatures, 1907*—Continued.

Date.	Locality.	Mean average effective temperature.	Number of weevils emerged.	Percentage of total emergence.
1907.		°*F*.		
May 3-9	Calvert	26.4	113	6.1
	Dallas	20.2	129	3.7
	Victoria	29.3	50	1.6
May 10-16	Calvert	31.9	59	3.2
	Dallas	24.0	121	3.5
	Victoria	32.5	26	.86
May 17-23	Calvert	35.5	54	3.0
	Dallas	31.2	103	3.0
	Victoria	31.8	17	.56
May 24-30	Calvert	33.0	49	2.6
	Dallas	23.3	20	.6
	Victoria	33.4	8	.26
May 31-June 6	Calvert	30.7	30	1.6
	Dallas	38.0	13	.4
	Victoria	30.9	21	.7
June 7-13	Calvert	43.2	10	.5
	Dallas	38.0	5	.15
	Victoria	40.0	2	.07
June 14-20	Calvert	37.4	5	.3
	Dallas	36.0	4	.12
	Victoria	36.8	1	.03
June 21-27	Calvert	39.4	1	.01
	Dallas			
	Victoria			

Total emergence:	
Calvert	1,842
Dallas	3,464
Victoria	3,026
Grand total	8,332

The large percentage of total emergence occurring during the first week of March is very striking and unquestionably also very exceptional. Only the extremely high range in temperature can explain this unusual record. Taking the average of the three locations, practically one-fourth of the total emergence occurred during the first week of March. During the following two weeks more than another one-fourth also emerged. During this period the temperatures averaged as high as they do ordinarily in May; and owing to the fact that a considerable majority of weevils had left shelter before the end of March the number emerging after that time shows a marked decrease.

It must not be supposed that these statements represent anything like usual conditions, although they unquestionably represent the facts in regard to emergence in 1907. The comparison of these records with those for Dallas and Keatchie (see p. 44) in 1906 will show clearly the exceptional nature of the variation.

It should be stated that when the emergence takes place as rapidly as was the case in March, 1907, the actual number of living weevils in the field may be expected to increase for some time because of the fact that a larger number of weevils is added to the total living on account of continued emergence than is lost on account of death among weevils which have previously emerged.

LONGEVITY OF WEEVILS AFTER EMERGENCE FROM HIBERNATION.

Preceding records have shown that on the average the weevils surviving hibernation had lived for over five months before their emergence. It is impossible to determine even approximately how old weevils may have been at the time they were placed in the hibernation cages. The longevity records here shown must, therefore, be very conservative. They may indicate very closely the average length of life of weevils which survive hibernation, but should not be considered as showing actually the maximum longevity. It has seemed advisable, therefore, to base the studies upon longevity after emergence from hibernation, since the exact dates for emergence and for deaths have been carefully determined.

As the weevils were collected daily from the cages, those found at each date must have emerged practically upon that date. It was the general practice to divide the weevils from each section of the cage into two lots of approximately equal numbers, one lot being placed in a series in which they received no food and the second lot being placed in a series which was supplied whatever stage of cotton was then available to weevils in the field where the experiments were being made. Thus, early in the season at Dallas, all weevils were necessarily placed in unfed series, since no cotton existed in the field. In each locality the first food consisted of the tender leaves of volunteer or sprout plants. As soon as squares were formed in the field these were supplied to the weevils in the fed series of experiments.

As a general rule the weevils emerging upon three consecutive days were placed in a cage bearing the same series designation, and the average date of emergence was considered as applying to the entire lot. This arrangement was necessary to reduce the amount of work required in caring for so many cages as would be needed to keep each day's weevils entirely separate.

In both the fed and unfed series frequent examinations were made to determine the time of death of each weevil, and fresh food was supplied to weevils in the fed series. Upon the death of a weevil its sex was determined and its period of life after emergence was also recorded. The manner in which sex can be positively determined is described in succeeding paragraphs. (See p. 91.) In this way the records for each lot bearing a serial number were kept by themselves and the results for each series are comparable with all others. While it would be most significant to present the records in the form of a summary of each series which would allow these comparisons to be seen, the necessity for abridging the tabular matter, so far as may be possible, prevents our doing so. Therefore for both the "unfed" and for the "fed" experiments we can give only the grand totals and averages with general statements based upon the tabular studies from which these figures are obtained.

LONGEVITY OF UNFED WEEVILS AFTER EMERGENCE FROM HIBERNATION.

Since the duration of life of unfed weevils was so much shorter than for fed weevils, the records of the former will be considered first. The principal object in the experiments with unfed weevils was to determine the time which they might survive while waiting for the growth of a food supply in the spring. The results have a most important special bearing upon the advisability of hastening or deferring the time of planting of cotton, especially when considered in connection with the period of emergence from hibernation. The figures given are based upon completed records only, all partial records having been discarded.

TABLE XLIII.—*Longevity of unfed weevils after emergence from hibernation, March to July, 1907.*

Locality.	Number of series tested unfed.	Total weevils emerged.	Weevils in series lots.			Maximum life.		Average duration of life.		
			Total.	♂	♀	♂	♀	♂	♀	Both sexes.
						Days.	*Days.*	*Days.*	*Days.*	*Days.*
Texas:										
Calvert	25	1,085	1,079	585	491	48	26	8.05	8.09	8.07
Dallas	19	2,317	2,179	1,178	1,009	90	88	13.00	11.09	12.50
Victoria	17	1,418	1,360	875	485	44	40	8.00	7.40	8.20
Total and average	61	4,820	4,618	2,638	1,988	90	88	10.30	9.80	10.10

The records both for maximum and average duration of life are very important. In the record showing maximum and average duration of life for each sex in each locality the time at Dallas exceeds by 50 per cent the time at either Calvert or Victoria. It should be stated that when weevils are kept in confinement it is probable that the most favorable conditions which can be furnished them can hardly be supposed to prolong their life beyond the normal condition in the field. Any unfavorable conditions in the cages will shorten the period. It was found in the course of the work that whenever sunshine was allowed to strike directly on the lantern globe breeding jars in which the weevils were for the most part confined, the heat and excessive humidity generated within the globe caused an abnormal activity among the weevils, and if prolonged or frequently repeated, it resulted in their early death. It was also found that in the breeding cages among the unfed weevils the degree of moisture was less than would normally occur on plants or at the surface of the ground in the field. This dryness also naturally shortens the life of weevils. In an experiment at Dallas series 14 was kept with plenty of moisture while series 15 was dry. Otherwise conditions in the two series were identical. The average life in the wet series was 20.3 days while in the dry series it was but 7.1 days. Other experiments pointed to the same conclusion.

These facts indicate that the records for Calvert and Victoria are probably considerably below the normal survival period for emerged weevils in the field, and the records for Dallas are at least conservative. The difference in duration of life between the males and females was but slight, but rather uniformly in favor of the males. In each locality the maximum longevity was shown by males. This fact agrees with previous conclusions regarding the relative duration of life of the two sexes. Apparently copulation does not materially affect the longevity of either sex. In this connection it may be stated that unquestionable instances of mating were found among weevils immediately after their emergence and before there was any possibility of their having fed. This was of rare occurrence, and the question of fertility resulting was not positively determined.

From the records it becomes evident that many emerged weevils may survive from six to twelve weeks without food and that the average survival for all weevils may be between one and two weeks.

There is some evidence to show that it is possible for these unfed weevils to move rather extensively in search of food, and undoubtedly this is done in many instances. Other observations, however, indicate that if food is not found in the vicinity of emergence the weevils may become quiet for a considerable period before again seeking food, and in this way their movement may occur only through comparatively short distances. It is also probable that when they first find a food supply they do not intentionally leave it in search of other plants which may be in a more advanced stage of growth.

As to the proportion of each sex among the weevils surviving in these experiments it appears that 57 per cent were males. The maximum longevity of any weevil was ninety days. This was a male which was kept under outdoor conditions from March 1, when it emerged, to May 30, when it died. The maximum life for a female was eighty-eight days. This weevil emerged April 25 and died July 20. The average temperature under which this lot of weevils was kept ranged between 45 and 60 degrees and the average length of life for all of the 55 weevils tested in series 17 at Dallas was slightly more than thirty days. This emphasized the important effect of temperature upon the period of survival without food.

The grand total for average duration of life shows 10.1 days for more than 4,600 weevils. The males lived on an average one-half day longer than did the females.

It would be both interesting and valuable if the records showing a summary of the results for each sex in each series of experiments could be presented in full. It is thought, however, that the corresponding records for the fed weevils have a greater value and it may be allowable to present in place of the full records for the unfed weevils merely a brief statement of the most important facts as to the survival of each sex.

The most apparent fact is that there is a consistent increase in duration of life without food in both sexes in a northern locality, as at Dallas, as compared with a southern locality, as at Victoria, while Calvert occupies an intermediate position both in the starvation period and geographically. Lower temperatures are obviously directly correlated to the degree of activity of the insects and thus determine directly the limit of endurance without food. But in no case is there any very marked variation between the sexes in the same locality.

It appears that practically two-thirds of all weevils died during the first ten days after their emergence. One-fourth of the total number tested lived to between eleven and twenty days. Beyond twenty days the percentage surviving becomes comparatively small, and between fifty and ninety days the percentage for each ten-day period is rather surprisingly uniform. It is very evident, however, that even in a season when the bulk of emergence may occur as unusually early as it did in 1907 it would be absolutely impossible to exterminate the weevil by any possible delay in the time of planting cotton.

LONGEVITY OF FED WEEVILS AFTER EMERGENCE FROM HIBERNATION.

The records indicating the longevity of weevils which were fed after their emergence from hibernation have been prepared in a similar way to show results comparable with those for unfed weevils which have just been given. They form the second part of the comparative series of experiments to determine longevity. The conditions of food supply, while kept as favorable as was possible, could not at best equal the natural conditions in the field, although the weevils were evidently saved the trouble which they might have experienced in the field of finding their first food supply. The considerations which have previously been mentioned in regard to the effect of high temperature and excessive moisture in the jars when exposed to sunshine apply with fully as much force to the fed as to the unfed series of experiments.

TABLE XLIV.—*Longevity of weevils fed after emergence from hibernation, March to September, 1907.*

Locality.	Number of series tested, fed.	Total weevils emerged.	Number of weevils in series.			Maximum life.		Average duration of life.		
			Total.	♂	♀	♂	♀	♂	♀	Both sexes.
Texas:										
Dallas	7	998	901	490	411	130	108	38.4	38.0	38.2
Calvert	26	740	715	363	352	92	118	29.2	30.7	30.0
Victoria	20	1,450	1,349	785	564	84	86	15.1	14.2	14.7
Total and average	53	3,188	2,965	1,638	1,327	130	118	25.2	25.9	25.5

Only about two-thirds as many weevils were carried through in the fed tests as in the unfed tests. Among the total of 2,965 weevils 55 per cent were males, while in the unfed experiments 57 per cent were males. The average duration of life shows but very slight variation between the sexes, both living between twenty-five and twenty-six days. This average is somewhat smaller than has previously been obtained in similar experiments, and this is probably due to the greater exposure to sunshine of the cages in which the weevils were kept in this series of experiments. The average period of life with food was about two and one-half times that without food.

Among the fed weevils, as among the unfed, the longest life occurred at Dallas. This also was a male weevil which emerged from hibernation on May 6 and survived until September 13, or one hundred and thirty days. The greatest length of life for a female occurred at Calvert. This weevil emerged on April 11 and died on August 7, having been active one hundred and eighteen days.

The full length of life of the last weevil dying in these experiments is also a matter of interest. This weevil was collected in the field at Dallas and placed in the hibernation cage on October 16, 1906. From that time until May 6, 1907, it had no food. The period from its collection until its death lacked but a day or two of being eleven months, during three-fifths of which period it existed without food. This is next to the longest lived boll weevil of which we have record, the longer record being slightly more than eleven months in the case of a male weevil hibernated at Victoria in 1903.

In a study of the emergence movement and of the duration of life of fed weevils by ten-day periods we have used the total number of weevils of each sex observed in each locality as the basis upon which we have determined the percentage of mortality occurring in each successive ten-day period. The full records for each locality have been omitted and only the totals for each sex in each locality have been included in Table XLV (p. 88). The emergence from hibernation was distributed through four months, or slightly more, in 1907. A study of the omitted records shows that, as a rule, the weevils living longest emerged at approximately the middle of the emergence movement. It is probable that these weevils were among those which entered hibernation at the most favorable period during the preceding fall and that they found also the most favorable class of shelter conditions to protect them during the winter. The importance of breaking up this succession of conditions, so favorable to the survival of weevils, their maximum length of life, and, consequently, their greatest injuriousness, need only be mentioned to be appreciated. That early fall destruction of stalks, the cleaning up of rubbish which might shelter weevils most favorably during the winter, and the early planting and uniform planting of the crop are all logical parts or steps in the rational method of fighting the boll weevil is plainly shown by these studies.

TABLE XLV.—*Comparison of summaries for longevity of fed weevils, by ten-day periods, in each locality.*

Locality.	Number of weevils in series.	Weevils dying within a period of— 1-10 days. Number.	1-10 days. Per cent.	11-20 days. Number.	11-20 days. Per cent.	21-30 days. Number.	21-30 days. Per cent.	31-40 days. Number.	31-40 days. Per cent.	41-50 days. Number.	41-50 days. Per cent.	51-60 days. Number.	51-60 days. Per cent.
MALE WEEVILS.													
Dallas	490	47	9.6	72	14.7	87	17.7	68	13.9	87	17.7	47	9.6
Calvert	363	86	23.8	61	16.9	60	16.7	50	13.8	49	13.5	41	11.3
Victoria	785	371	47.3	216	27.6	116	14.8	39	5.0	14	1.8	13	1.7
Total and average.	1,638	504	30.2	349	21.3	263	16.0	157	9.6	150	9.2	101	6.2
FEMALE WEEVILS.													
Dallas	411	32	7.8	54	13.1	91	22.1	46	11.2	91	22.1	37	9.0
Calvert	352	67	18.8	63	17.7	60	16.7	58	16.3	54	15.2	32	9.0
Victoria	564	293	51.9	133	23.5	88	15.6	24	4.3	11	2.0	10	1.8
Total and average.	1,327	392	29.5	250	18.8	239	18.0	128	9.6	156	11.7	79	5.9
WEEVILS OF BOTH SEXES.													
Total and average, 2,967		896	30.2	599	20.2	502	16.9	285	9.6	306	10.3	180	6.1

Locality.	Number of weevils in series.	Weevils dying within a period of— 61-70 days. Number.	61-70 days. Per cent.	71-80 days. Number.	71-80 days. Per cent.	81-90 days. Number.	81-90 days. Per cent.	91-100 days. Number.	91-100 days. Per cent.	Over 100 days. Number.	Over 100 days. Per cent.
MALE WEEVILS.											
Dallas	490	36	7.3	31	6.3	5	1.0	7	1.5	2	0.4
Calvert	363	7	1.9	6	1.7	2	1.6	2	.6	0	......
Victoria	785	4	.5	8	1.0	3	.4	0	......	......	......
Total and average.	1,638	47	2.9	45	2.8	10	.6	9	.6	2	.1
FEMALE WEEVILS.											
Dallas	411	32	7.8	22	5.4	4	1.0	1	0.2	1	0.2
Calvert	352	9	2.5	3	.8	5	1.4	2	.6	1	.3
Victoria	564	4	.7	1	.2	1	.2	0	......	0	......
Total and average.	1,327	45	3.4	26	2.0	10	.8	3	.2	2	.1
WEEVILS OF BOTH SEXES.											
Total and average, 2,965		92	3.1	71	2.4	20	0.7	12	0.4	4	0.1

At Dallas the number of weevils surviving for two months or more amounted to 15.6 per cent of the total number observed. Practically 50 per cent of each sex survived for more than six weeks.

At Calvert 15 per cent of the total number of weevils survived over fifty days and 50 per cent for more than thirty days. The average life at Calvert was nearly ten days less than at Dallas. It is very noticeable that those weevils which lived longest at Calvert emerged during about the middle of the emergence period. The weevils which were very late in emerging survived for only a short time. The decrease in the percentage of survival is markedly regular from the first ten days to the end of the period. The most decided decrease occurs between sixty and seventy days.

The maximum longevity at Victoria fell considerably short of that at Calvert and Dallas. In this case 15 per cent of the weevils survived beyond only about twenty-five days and nearly 50 per cent died during the first ten days. The reason for the marked shortening of life at Victoria was undoubtedly the greater exposure to sunshine of the jars in which the weevils were confined.

This comparison shows that length of life uniformly averages longer in northern Texas than in either central or southern Texas. At Dallas 3 weevils, at Calvert 1, and at Victoria none lived more than one hundred days. At Dallas 11 weevils, at Calvert 5, and at Victoria none lived more than ninety days. From the grand summary of the records in both sexes it appears that among approximately 3,000 weevils 50 per cent died during the first twenty days. Two-thirds of them died in the first thirty days and three-fourths of them in the first forty days.

From these records it appears that any kind of a food supply will serve to maintain a majority of the emerging weevils for more than three weeks. This consideration has a special significance in southern Texas, where sprout and volunteer cotton usually occur. This subject will be further considered in the relation of hibernated weevils to food supply.

BEARING OF OBSERVATIONS ON FED AND UNFED WEEVILS ON THE POSSIBILITY OF AVOIDING DAMAGE TO COTTON BY LATE PLANTING.

One of the most important features of the experiments on the longevity, with and without food, of weevils that have survived the winter, is the bearing that the results have on the theory of late planting of cotton to avoid damage. This theory has been propounded by numerous persons ever since 1895.

In the series of experiments with unfed weevils 4,600 individuals were used; in the series with fed weevils 2,965. The unfed series is the more important with reference to late planting, The maximum length of life of the unfed weevils emerging in February, 1907, was

14 days; the average 6.9 days. The maximum of the individuals emerging in March was 51 days; the average 16.9 days. For the April-emerging weevils the maximum was 46 days; the average 21.2. For the May-emerging weevils the maximum 33; the average 15.8 days. Of the June-emerging weevils maximum 12 days; the average 7.4. It will be seen that even in such an abnormal season as 1907 weevils emerging any time during the month of May might be expected to live for at least 15 days and individuals emerging at any time during the month of June to live for more than 7 days. It is thus clear that many weevils emerging in May would survive without any food whatever until considerably after the middle of June and that those of the June emergence would survive in many cases beyond the first of July.

It is important to note that a considerable percentage of the emerging weevils did not appear until late. For instance, 10.2 per cent of all the weevils which survived at Calvert did not appear until between May 10 and June 6. At Dallas the percentage for this period was 7.5, and at Victoria, 2.38.

The observations on the longevity of the fed weevils also has a bearing on late planting, since there is always some volunteer cotton around seed houses and elsewhere that will be found by the weevils. The maximum length of life of the fed weevils which appeared in February was 47 days, the average 45 days; of March-appearing weevils the maximum 93 days, average 45.5 days; of April-appearing weevils maximum 82 days, average 46.5 days; of May-appearing weevils maximum 86 days, average 55 days; of June-appearing weevils maximum 46 days, average 37.8 days.

The longevity of the weevils emerging in May and June is most important. The average survival of 55 days in one case and the 37.8 in the other shows that with such food as can easily be obtained, at least some of the emerging weevils would be carried over until far into the summer, even if no cotton were planted.

The records just referred to are, of course, a sufficient refutation of the theory that the weevil could be "starved out" by late planting. It has been proposed, however, that the number of weevils surviving to damage late-planted cotton would be relatively so small that such cotton would have a better chance to mature a crop than that planted earlier. In order to test this matter the Bureau of Entomology has conducted practical field tests in which cotton has been planted about the 10th of June. In one season four of these experiments were performed in parts of Texas showing distinct climatic features and one in Louisiana in cooperation with the State Crop Pest Commission. In every case the yield was cut down so severely by the weevils that survived the prolonged period in which no cotton was to be found that the impossibility of producing cotton in that way was fully demonstrated.

SEX OF WEEVILS SURVIVING HIBERNATION.

We found it possible to readily and accurately recognize male and female weevils without a partial dissection. In comparatively few species of weevils are the males and females so closely similar in general external character as in the case of the Mexican cotton boll weevil. It was found that size depended primarily upon the food supply of the larva and that it had no special significance in regard to sex, although it appears that the average male is slightly smaller than the average female. There exists a rather wide variation also in coloration, which also proved to depend upon food supply and age rather than upon sex.

SECONDARY SEXUAL CHARACTERS.

We are indebted to Dr. A. D. Hopkins, of the Bureau of Entomology, for indicating the most strongly marked points of difference in the secondary sexual characters of the boll weevil. The distinctive

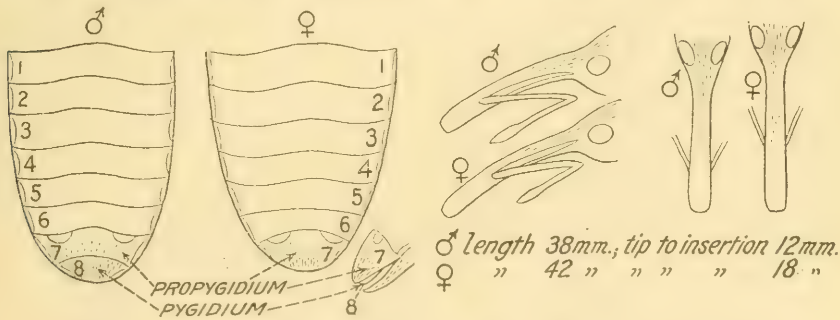


FIG. 9.—Secondary sexual characters of *Anthonomus grandis*. (After Hopkins.)

characters (see fig. 9) are found upon the snout and upon the dorsal side of the last two abdominal segments, which are normally almost completely hidden by the wing covers. The differences are subject to some variation but are still sufficiently constant to enable a close observer to positively separate males from females with the aid of a hand lens. Since these points of distinction have not previously been published it seems advisable to include them here, as they furnish the basis for the determinations of sex which follow.

Female.—The snout of the female is slightly longer and more slender than that of the male. It usually tapers slightly from each end toward the middle when viewed from above. The antennæ are inserted slightly farther from the tip than is the case in the male. The insertion is at about two-fifths of the distance from the tip of the snout to the eyes. As a rule the surface of the snout is more smooth and shining than in the male. A slight depression, rather elongated and much larger than any of the other punctures upon the snout, occurs between the bases of the antennæ. When the wing covers and wings are unfolded the abdomen shows seven distinct dorsal segments. The last segment visible from above in the female is called the propygidium. In the female this covers the terminal segment or pygidium, which can be seen only from the sides.

Male.—Snout slightly shorter, thicker, and more coarsely punctured than in the female. The depression mentioned in the female is lacking. The antennæ are inserted at practically one-third of the distance from the tip of the snout to the eyes. The sides of the snout are very nearly parallel. In the abdomen the male shows eight distinct dorsal segments, the terminal segment (pygidium) not being covered by the propygidium as is the case in the female.

In general practice an examination of the snout is sufficient to determine the sex of each weevil.

PROPORTION OF SEXES SURVIVING HIBERNATION.

The records here given as to the proportion of sexes surviving hibernation are confined to determinations of sex for positively hibernated adults.

TABLE XLVI.—*Sex of weevils surviving hibernation in Texas.*

Year.	Locality.	Male.		Female.	
		Number determined.	Percentage of total examined.	Number determined.	Percentage of total examined.
1903	Several places	269	60.7	174	39.3
1904	Calvert	40	60.0	27	40.0
1904	Victoria	42	66.7	21	33.3
1904	do	161	55.0	132	45.0
1906	do	84	59.6	57	40.4
1907	Dallas	1,668	54.2	1,412	45.8
1907	Calvert	948	53.0	846	47.0
1907	Victoria	1,660	61.3	1,049	38.7
	Total and average	4,872	[a] 56.7	3,718	[a] 43.3

[a] Weighted average.

While these records show considerable variation in the proportion of the sexes for different localities and during different seasons, there is a uniformity in the general preponderance of males. In the total of 9,000 weevils examined 53.6 per cent were males. This proportion corresponds quite closely to that found to exist among weevils entering hibernation (see pp. 16–17). It is evident, therefore, that the preponderance of males in the spring is not due to any superior power of endurance enabling them to hibernate more successfully than females. Apparently there is little, if any, difference in respect to the ability of the two sexes to hibernate successfully.

From a knowledge of the habits of the adults it appears that the preponderance of males in the spring is a favorable provision of nature, making it more certain for the sexes to mate and to insure reproduction. In spite of a number of attempts to obtain a definite answer to the question whether it is absolutely necessary for copulation to occur in the spring before females can reproduce, this point has not been positively settled. There are indications, however, that in most, if not all, cases this is essential. The fact that mating occasionally occurs immediately after emergence but before either sex has fed in the spring has previously been noted. Unfertilized females at any season of the year deposit nearly all of their eggs upon the outside of squares or bolls, where they quickly dry up. No sign of parthenogenesis has been found. The meeting of males and females is to a large degree accidental, and during a season when weevils are comparatively scarce it is likely that in very many cases the sexes fail to come together or the meeting may be delayed for a considerable period.

Experiments have shown that the male weevils do not actively seek the females. They seem to recognize their presence through a distance of hardly more than an inch. The meeting of the sexes depends therefore largely upon their coming into close proximity upon a cotton plant. Since the males are less active in their movement than are the females, the value of the existence of a majority of males becomes apparent. The larger number of males and the more active habits of the females serve to increase the chances for the meeting of the sexes in the spring without materially decreasing the power of multiplication of the species.

RELATION OF HIBERNATED WEEVILS TO FOOD SUPPLY.

The relation of hibernated weevils to food supply is an important subject, since the reproduction and multiplication of the species depend primarily upon this point. As has been shown in numerous places the emergence period of the weevil practically coincides with the average period in the planting of cotton. The long duration of emergence makes it practically impossible to secure the planting of the entire crop either earlier or later than the emergence period of the weevil. It has been found both from the study of the weevil and from large-scale experiments in the culture of cotton that during nearly every season there is a decided advantage in planting the crop as early as soil and climatic conditions may permit. Too much emphasis can not be placed upon the fact that, at whatever time the cotton in a locality may be planted, there will be a decided advantage in having it all planted at as near a uniform date as is possible. It is obvious that this will entirely prevent the development of weevils until practically all of the crop begins fruiting. In this way the fruiting of the plant may take place most rapidly during the period of development of the first and second generations of weevils.

Early planted fields, although they may serve to attract, in some small degree, the weevils from surrounding fields, will almost invariably produce larger yields than later planted fields in the same locality. The reason for this is, primarily, the longer period which intervenes between the beginning of setting fruit with its coincident reproduction of weevils and the time when maximum infestation of the field occurs. Comparatively few weevils appear to move from one field of cotton to another until after maximum infestation takes place.

Repeated experiments in deferring the planting time of cotton have invariably resulted in small and comparatively unprofitable crops.

Extended observations made during the spring of 1906 showed that volunteer[a] cotton occurred very commonly in fields and yards, along roadsides, and around ginneries and seed houses in every one of the seventeen localities examined about the middle of May, representing territory then infested by the weevil and also extending outside the infested territory into Mississippi, Arkansas, and Tennessee. This makes it practically certain that volunteer[a] cotton occurs everywhere throughout the cotton-growing area, and it may therefore have considerable significance in supplying emerged weevils with their first food in spring.

Extensive examinations have also shown that sprout[a] cotton commonly occurs throughout the southern half of the weevil-infested area in Texas during the average season. As a rule the development of this takes place several weeks in advance of the average planted cotton, and it becomes therefore a very important factor in maintaining hibernated weevils and in the development of their first progeny. Although attention has repeatedly been called to this fact, large quantities of sprout cotton are still allowed to grow unchecked. It is doubtful whether it is advisable to cultivate this even where it amounts to half a stand. Wherever scattering plants occur in a field of planted cotton they should certainly be chopped out as quickly as they occur. The profit to be derived from them is nothing when compared with the great damage which their presence may inflict upon the remainder of the crop through providing the earliest opportunities for the reproduction and multiplication of the weevils.

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[a] The term "volunteer" is restricted to that class of cotton coming from the accidentally scattered seed of a preceding crop. Sprout cotton, also called stubble or seppa cotton, is a sprout growth from old cotton roots occurring during the winter or subsequent spring.

SUMMARY AND CONCLUSIONS.

Hibernation is the term used to designate those phases in the life and seasonal history of the boll weevil (or of any other animal or plant) which are concerned with its existence through the winter and the manner in which the species is protected or maintained in passing from one season to the next. Food, climatic, and shelter conditions are the principal factors concerned in hibernation.

Food conditions in the fall govern largely the abundance of individuals which may enter hibernation and therefore affect the abundance of the species in the following spring, since climatic and shelter conditions govern largely the proportion of the hibernating individuals which may survive.

A large majority of the weevils developed in a field during the season are produced from squares.

Weevils becoming adult comparatively late in the season are more likely to survive hibernation than are those which have been active for a number of weeks before the time arrived for them to hibernate successfully.

It is possible that offspring of each of the four or five generations which are produced on the average may survive to enter hibernation.

No "top crop" can reasonably be expected within the weevil-infested area.

All stages of the weevil may enter hibernation and under exceptionally favorable climatic conditions larvæ which are more than half grown may complete their development if in bolls and become mature during the hibernation period. Immature stages in squares rarely survive. Nearly all of the weevils surviving were adult before the beginning of the hibernation period.

The destruction of stalks in the fall, as long as possible before the normal hibernation time, is the most economical and effective method known for reducing the number of weevils entering hibernation.

"Entrance into hibernation" denotes the beginning of the generally inactive period, but it does not necessarily imply a change of position for the individuals involved. For the species and often also for the individual it is a gradual process depending primarily upon temperature conditions. The duration of the entrance period for the species depends upon the severity of the drop in temperature below about 43 degrees of mean average temperature. This period usually occurs coincidently with the first killing frosts and extends through a period of about twenty-five days.

From close examination of 1,750 weevils it seems that about 60 per cent of those entering hibernation are males.

The number of weevils per acre or per plant which may enter hibernation depends especially upon preceding climatic and food conditions and has been found to vary in different seasons and localities, occasionally being as high as 50,000 weevils per acre, or an average of from 7 to 10 weevils per plant. An average of the results in 17 of the most carefully studied fields shows 8,552 weevils per acre, or slightly more than 1 weevil per plant.

The proportion between the numbers of weevils hibernating on the stalks and among rubbish scattered on the surface of the ground changes as the season advances, the number on the stalks decreasing.

Great mortality occurs soon after the weevils enter hibernation, especially among those upon the surface of the ground.

Hibernation usually takes place as the mean average temperature falls below 55 degrees and may remain complete until the mean temperature rises above 60 degrees.

Weevils may avail themselves of almost any kind of shelter, and the favorable character of the shelter in relation to prevailing climatic conditions will influence the percentage of survival. Many pass the winter sheltered by the old bolls that remain hanging upon the stalks. The percentage of survival in bolls decreases generally from southern to northern Texas. Bolls are frequently so important a factor in shielding weevils from one season to another that it is advisable to destroy them as a regular practice even in northern Texas.

Exceptionally cold and wet winter weather is most unfavorable for weevil survival. The destruction of possible shelter through clean culture in the fall is an effective way of reducing weevil injury to the following crop. The shelter to be found in timber fringes around cotton fields is much more difficult to remove or control than is that within the fields. The importance of such unavoidable conditions may be minimized by judicious cleaning up and by rotation of crops.

Occasionally weevils may survive in stored cotton seed and be distributed along with it at planting time. This fact justifies the maintenance of quarantine regulations against the free movement from infested to uninfested territory of cotton seed and closely related cotton products which are apt to shelter weevils.

Most of the information obtained in regard to the hibernation of the weevil has resulted from cage experiments in which the influential conditions could be separated and to some degree brought under control.

During the winter of 1902–3, at Victoria, Tex., in the small-cage experiments with 356 weevils, an average of about 11 per cent survived. During the following season, also at Victoria, among 400 weevils but one-fourth of 1 per cent survived. During the winter of 1904–5 larger numbers of weevils were under observation at each of six localities ranging from the southern to the northern portions of the infested area. This was the season of most exceptional rainfall and cold, and it was not surprising that no weevils survived in the cage tests except at Victoria, which was the southernmost point of experiment. An average for the six localities shows a survival of less than two-thirds of 1 per cent. In the small-cage work of 1905–6 there was an average survival of 1.3 per cent, and practically all of this occurred in the outdoor cages.

The most important work done in 1905–6 was in a large cage at Keatchie, La., where 25,800 weevils were placed in 18 compartments. The survival in this cage was 2.82 per cent, and the emergence occurred between March 22 and June 28, 1906. The cages having nearest to the ordinary field conditions with poor cultivation gave the largest percentage of successful hibernation. A study of the emergence and temperature records for similar experiments at Dallas, Tex., and Keatchie, La., shows that at the former place approximately 50 per cent of the emergence occurred while the temperature ranged between 58 and 68 degrees, while at the latter place one-half of the total emergence took place while the temperature ranged between about 65 and 75 degrees. Very few weevils emerged while the temperature was below 57 degrees.

There is an optimum period for entrance into hibernation, and weevils entering during this period have a considerably better chance of surviving than do those which enter either earlier or later. If hibernation is begun earlier than this optimum period, it is likely that emergence will be completed earlier during the following season, and also if entrance occurs later than this period it is likely that emergence will begin unusually early in the following spring.

Variation in the period of entrance into hibernation and the difference in the nature of the shelter secured by the weevils may reasonably account for the variations found in the amount of accumulated effective temperature required to produce complete emergence in the spring.

Weevils emerging earlier in the season survived for a longer period than did those which emerged after the middle of the emergence period. It is a common occurrence for weevils to leave their winter quarters upon warm days in spring, returning again to a condition of inactivity for a period of several days or even weeks. Disappearance and reappearance in the case of plainly marked individuals has been observed to occur as many as eight times, and a maximum period of forty-three days between appearances has been recorded. These facts argue very strongly indeed against the proposition which is sometimes made by those who are not thoroughly familiar with the habits of the weevil, to starve the emerged weevils by deferring the planting of cotton in the spring. Two lots of 20 and 8 weevils survived for an average of thirty and sixty days, respectively, after emergence without a particle of green food from the time of their entrance into hibernation to the time of their death. Other tests show similar results.

The hibernation experiments of 1906–7 consisted of large-cage work in three localities representing the northern, central, and southern portions of the infested area. Each cage inclosed 10 separate experiments and the comparisons made possible by the three locations, the different shelter conditions, and the different dates of instituting the experiments furnish the basis for the most complete and significant work which has been done with the hibernation of the weevil.

Owing to the exceptional mildness of this season, complete hibernation did not occur at any time during the winter in any part of Texas. Emergence began during the last week or ten days of February, 1907. At Dallas 7.8, at Calvert 10.5, and at Victoria 27.7 per cent of the total numbers of weevils placed in the cages were counted as being active at some time during the winter season when they should normally have all been in complete hibernation. About 13 per cent of the adult weevils buried with a lot of bolls under 2 inches of heavy, black soil escaped and were found upon the cage screen during the next few days. Weevils were active in the field as well as in the cages during this winter. The period of greatest emergence occurred during the latter part of March, which was undoubtedly from four to six weeks earlier than is usual. Succeeding low temperatures served to prolong the period of emergence until the 1st of July. In the three localities under observation an average of 11.5 per cent of the 75,000 weevils placed in the experiments survived and emerged in the spring of 1907.

Grouping the experiments in the three localities according to the dates of installation of the weevils and averaging the percentages of survival in each group, it appears that there was a steady increase in this percentage upon succeeding dates after the middle of October, when the experiments were started, to the end of November, when the last weevils were placed in the cages. This increase is so nearly regular as to prove conclusively that the date at which weevils are deprived of food in the fall, in its relation to the most favorable period for entrance into hibernation, has a most vital influence upon the prospect for survival. Among the weevils started October 14 but 3.14 per cent survived, while among those started just one month later an average of 19.67 per cent survived. These results prove absolutely the advisability of destroying the food supply of the weevils at least three weeks before the usual time for the first frosts to occur, and they show very plainly just why such a practice is the most effective method yet found for reducing the number of weevils that may survive the winter to attack the crop of the following season. This portion of the bulletin, especially, should be carefully studied in detail.

The survival in the various sections of the cages in the three localities ranged from 1.89 to 31.34 per cent. The average survival in each of the localities was as follows: Calvert, 9.49 per cent; Dallas, 11.22 per cent; Victoria, 13.47 per cent.

At Dallas the largest percentage of survival occurred in a section of the cage having an abundance of fallen leaves, in which the weevils were placed on November 15 and with the cotton stalks left standing. The smallest survival occurred in a section having fully as favorable shelter conditions but in which the weevils were placed on October 13 and left without any food from October 15.

At Victoria the largest survival occurred among weevils started on November 6 without food in the section provided with Spanish moss and bark.

The winter was too mild to furnish any comparative test of the favorableness of various shelter conditions, but in general it appears that fallen leaves, Spanish moss, and a heavy growth of grass are most favorable to the weevils wherever they may occur.

Temperature conditions were practically normal during November, 1906, and the most favorable time for entrance into hibernation was between November 12 and 15 at Dallas and slightly later at the more southern points.

In each locality the maximum longevity was shown by males, and the average duration of life of that sex was also slightly in excess of that of females. The average survival of all weevils kept without food was about ten days, and a considerable number lived to between six and twelve weeks after emergence. The maximum survival for any unfed weevil was ninety days. Obviously there is no chance to starve out all weevils by any possible delay in planting.

Among the fed weevils the longest-lived was also a male which was active for one hundred and thirty days after its emergence. The longest-lived female was active for one hundred and eighteen days. The average active life for all fed weevils was 25.5 days after emergence. Practically one-half of all fed weevils lived for more than six weeks in the spring.

The sex was determined for more than 8,500 weevils which had survived the winter, and it was found that 56.7 per cent of these were males. There is an invariable preponderance of males both in the fall upon entering hibernation and in the spring upon emergence therefrom.

Reproduction can not begin until the first squares become at least half grown. At whatever date cotton may be planted in a locality, there is a decided advantage in having it all planted at as nearly a uniform date as is possible. As a rule early-planted fields yield better than do those planted later, but with similar conditions of seed, soil, and cultivation. All volunteer and sprout cotton developing in advance of the main crop should be destroyed before it forms squares, since otherwise it may furnish the weevils with opportunities for reproduction for some time before squares become common and thereby unnecessarily, early in the season, increase their numbers and the resultant injury to the main crop.

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U. S. DEPARTMENT OF AGRICULTURE,
BUREAU OF ENTOMOLOGY—BULLETIN No. 78.
L. O. HOWARD, Entomologist and Chief of Bureau

ECONOMIC LOSS TO THE PEOPLE OF THE UNITED STATES THROUGH INSECTS THAT CARRY DISEASE.

BY

L. O. HOWARD, PH. D.
Entomologist and Chief of Bureau.

ISSUED MARCH 18, 1909.

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LETTER OF TRANSMITTAL.

U. S. DEPARTMENT OF AGRICULTURE,
BUREAU OF ENTOMOLOGY,
Washington, D. C., January 15, 1909.

SIR: I have the honor to recommend for publication as Bulletin 78 of this Bureau the accompanying manuscript entitled "Economic Loss to the People of the United States Through Insects that Carry Disease."

The United States is just awakening to a knowledge of the disastrous results following a lack of appreciation of the danger arising from the unchecked development of mosquitoes and the typhoid fly, and it is hoped that this bulletin will not only emphasize this danger, but will also lend support to movements, both local and widespread, toward the destruction (often so easy) of these carriers of disease.

Respectfully,

L. O. HOWARD,
Entomologist and Chief of Bureau.

Hon. JAMES WILSON,
Secretary of Agriculture.

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ECONOMIC LOSS TO THE PEOPLE OF THE UNITED STATES THROUGH INSECTS THAT CARRY DISEASE.

INTRODUCTION.

It has been definitely proven and is now generally accepted that malaria in its different forms is disseminated among the individuals of the human species by the mosquitoes of the genus Anopheles, and that the malarial organism gains entrance to the human system, so far as known, only by the bite of mosquitoes of this genus. It has been proven with equal definiteness and has also become generally accepted that yellow fever is disseminated by the bite of a mosquito known as *Stegomyia calopus* (possibly by the bites of other mosquitoes of the same genus), and, so far as has been discovered, this disease is disseminated only in this way. Further, it has been scientifically demonstrated that the common house fly is an active agent in the dissemination of typhoid fever, Asiatic cholera, and other intestinal diseases by carrying the causative organisms of these diseases from the excreta of patients to the food supply of healthy individuals; and that certain species of fleas are the active agents in the conveyance of bubonic plague. Moreover, the tropical disease known as filariasis is transmitted by a species of mosquito. Furthermore, it is known that the so-called "spotted fever" of the northern Rocky Mountain region is carried by a species of tick; and it has been demonstrated that certain blood diseases may be carried by several species of biting insects. The purulent ophthalmia of the Nile basin is carried by the house fly. A similar disease on the Fiji Islands is conveyed by the same insect. Pink eye in the southern United States is carried by minute flies of the genus Hippelates. The house fly has been shown to be a minor factor in the spread of tuberculosis. The bedbug has been connected with the dissemination of several diseases. Certain biting flies carry the sleeping sickness in Africa. A number of dangerous diseases of domestic animals are conveyed by insects. The literature of the whole subject has grown enormously during the past few years, and the economic loss to the human species through these insects is tremendous. At the same time, this loss is entirely unnecessary; the diseases in question can be controlled, and the suppression of the conveying insects, so absolutely vital with certain of these diseases and so important in the others, can be brought about.

MOSQUITOES.

Entirely aside from the loss occasioned by mosquitoes as carriers of specific diseases, their abundance brings about a great monetary loss in other ways.

Possibly the greatest of these losses is in the reduced value of real estate in mosquito-infested regions, since these insects render absolutely uninhabitable large areas of land available for suburban homes, for summer resorts, for manufacturing purposes, and for agricultural pursuits. The money loss becomes most apparent in the vicinity of large centers of population. The mosquito-breeding areas in the vicinity of New York City, for example, have prevented the growth of paying industries of various kinds and have hindered the proper development of large regions to an amount which it is difficult to estimate in dollars and cents and which is almost inconceivable. The same may be said for other large cities near the seacoast, and even of those inland in low-lying regions. The development of the whole State of New Jersey has been held back by the mosquito plague.

Agricultural regions have suffered from this cause. In portions of the Northwestern States it has been necessary to cover the work horses in the field with sheets during the day. In the Gulf region of Texas at times the market value of live stock is greatly reduced by the abundance of these insects. In portions of southern New Jersey there are lands eminently adapted to the dairying industry, and the markets of New York, Philadelphia, and the large New Jersey cities are at hand. In these localities herds of cattle have been repeatedly established, but the attacks by swarms of mosquitoes have reduced the yield of milk to such an extent as to make the animals unprofitable, and dairying has been abandoned for less remunerative occupations. The condition of the thoroughbred race horses at the great racing center, Sheepshead Bay, Long Island, was so impaired by the attacks of mosquitoes as to induce those interested to spend many thousands of dollars a few years ago in an effort to abate the pest.

All over the United States, for these insects, and for the house fly as well, it has become necessary at great expense to screen habitations. The cost of screening alone must surely exceed ten millions of dollars per annum.

MALARIA.

The west coast of Africa, portions of India, and many other tropical regions have always, at least down to the present period, been practically uninhabitable by civilized man, owing to the presence of pernicious malaria. The industrial and agricultural development of Italy has been hindered to an incalculable degree by the prevalence of malaria in the southern half of the Italian peninsula, as well as in the valley of the Po and elsewhere. The introduction and spread of malaria in Greece is stated by Ronald Ross, and with strong reasons, to have been largely responsible for the progressive physical degeneration of one of the strongest races of the earth.

In the United States, malaria, if not endemic, was early introduced. The probabilities are that it was endemic, and it is supposed that the cause of the failure of the early colonies in Virginia was due to this disease. It is certain that malaria retarded in a marked degree the advance of civilization over the North American Continent, and particularly was this the case in the march of the pioneers throughout the Middle West and throughout the Gulf States west to the Mississippi and beyond. In many large regions once malarious the disease has lessened greatly in frequency and virulence owing to the reclamation of swamp areas and the lessening of the number of the possible breeding places of the malarial mosquitoes, but the disease is still enormously prevalent, particularly so in the southern United States. There are many communities and many regions in the North where malaria is unknown, but in many of these localities and throughout many of these regions Anopheles mosquitoes breed, and the absence of malaria means simply that malarial patients have not entered these regions at the proper time of the year to produce a spread of the malady. It has happened again and again that in communities where malaria was previously unknown it has suddenly made its appearance and spread in a startling manner. These cases are to be explained, as happened in Brookline, Mass., by the introduction of Italian laborers, some of whom were malarious, to work upon the reservoir; or, as happened at a fashionable summer resort near New York City, by the appearance of a coachman who had had malaria elsewhere and had relapsed at this place. In such ways, with a rapidly increasing population, malaria is still spreading in this country.

To attempt an estimate of the economic loss from the prevalence of malaria in the United States is to attempt a most difficult task. Prof. Irving Fisher, in one of his papers before the recent International Tuberculosis Congress, declared that tuberculosis costs the people of the United States more than a billion dollars each year. In this estimate Professor Fisher considered the death rate for consumption, the loss of the earning capacity of the patients, the period of invalidism, and the amount of money expended in the care of the sick, together with other factors. In making these estimates he had a much more definite basis than can be gained for malaria. The death rate from malaria (as malaria) is comparatively small and is apparently decreasing. Exact figures for the whole country are not available. From a table comprising 22 cities it appears that two-thirds of the deaths from malaria in the United States occur in the South—one-third only in the North. The death rate from malaria by States is available only for the following registration States: California, Colorado, Connecticut, District of Columbia, Indiana, Maine, Maryland, Massachusetts, Michigan, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, South Dakota, and Vermont, all of which are Northern States. For these States the census reports from 1900 to 1907, inclusive, give the following death rates:

TABLE I.—*Deaths due to malaria in the registration States, 1900–1907.*

Year.	Number of deaths from malaria per 100,000 population.	Total deaths from malaria.	Year.	Number of deaths from malaria per 100,000 population.	Total deaths from malaria.
1900	7.9	2,434	1905	3.9	1,321
1901	6.3	1,791	1906	3.5	1,415
1902	5.4	1,738	1907	2.8	1,166
1903	4.3	1,410			
1904	4.2	1,391		....	12,666

Estimating, from the preceding table, the average annual death rate due to malaria at 4.8 per 100,000 population, and considering that the registration area includes only 16 of the Northern States (assuming fairly, however, that the death rate in the other Northern States is the same), it seems reasonably safe to conclude that the death rate from malaria for the whole United States must surely amount to 15 per 100,000. It is probably greater than this, since the statistics from the South are city statistics, and malaria is really a country disease. Thus it is undoubtedly safe to assume that the death rate for the whole population of the United States is in the neighborhood of 15 per 100,000. This would give an annual death rate from malaria of nearly 12,000 and a total number of deaths for the 8-year period 1900–1907 of approximately 96,000.

But with malaria perhaps as with no other disease does the death rate fail to indicate the real loss from the economic point of view. A man may suffer from malaria throughout the greater part of his life, and his productive capacity may be reduced from 50 to 75 per cent, and yet ultimately he may die from some entirely different immediate cause. In fact, the predisposition to death from other causes brought about by malaria is so marked that if, in the collection of vital statistics, it were possible to ascribe the real influence upon mortality that malaria possesses, this disease would have a very high rank in mortality tables. Writing of tropical countries, Sir Patrick Manson declares that malaria causes more deaths, and more predisposition to death by inducing cachectic states predisposing to other affections, than all the other parasites affecting mankind together. Moreover, it has been shown that the average life of the worker in malarious places is shorter and the infant mortality higher than in healthy places.

But, aside from this vitally important aspect of the subject, the effect of malaria in lessening or destroying the productive capacity of the individual is obviously of the utmost importance, and upon the population of a malarious region is enormous, even under modern conditions and in the United States. It has been suggested that the depopulation of the once thickly settled Roman Campagna was due to the sudden introduction of malaria by the mercenaries of Scylla and Marius. Celli, in 1900, states that owing to malaria about 5,000,000 acres of land in Italy remain—not uncultivated, but certainly very imperfectly cultivated. Then also, in further example, in quite recent years malaria entered and devastated the islands of Mauritius and Réunion, practically destroying for a time the productiveness of these rich colonies of Great Britain and France.

Creighton, in his article on malaria in the Encyclopædia Britannica, states that this disease "has been estimated to produce one-half of the entire mortality of the human race; and inasmuch as it is the most frequent cause of sickness and death in those parts of the globe that are most densely populated, the estimate may be taken as at least rhetorically correct."[a]

Is it possible to make any close estimate of the ratio between the number of deaths from malaria and the number of cases of the same malady? No perfectly sound basis for such an estimate is apparent. In the English translation of Celli's work on "Malaria According to the New Researches," published in London in 1900, it is stated that the mortality from malaria in Italy from 1887 to 1898 varied from 21,033 in the first-named year to 11,378 in the last-named year, and the mean mortality for the period is assumed to be about 15,000. In 1896 a count of the patients in the hospitals in Rome was made, and the mortality rate of 7.75 per thousand of the actual patients was established. Calculating then on this basis, and at this rate, the number of cases per year for Italy was placed at about 2,000,000. According to this estimate, and with the average mortality for the United States of 12,000 as above indicated, the approximate number of cases for the United States would be about 1,550,000. It seems obvious, however, that Celli, in using the basis of hospital patients only, must have underestimated the number of cases for the Kingdom, since of the people in the country suffering from malaria the proportion entering the hospital must be relatively small. Therefore the death rate from malaria of malarial patients in the hospital must be greater than the death rate from malaria of the people who suffer from this disease in the whole country. In fact, so great must this

[a] See "Darwinism and Malaria," by R. G. Eccles, M. D., Medical Record, New York, January 16, 1909, pp. 85–93.

discrepancy necessarily be that it would not seem at all unlikely to the writer if the number of persons suffering from malaria in Italy were in reality nearer 3,000,000 than 2,000,000.

The same argument will hold for the United States, and more especially so since as a rule malaria in this country is of a lighter type than in Italy; in fact an estimate of 3,000,000 cases of malaria in the United States annually is probably by no means too high. It will not be an exaggeration to estimate that one-fourth of the productive capacity of an individual suffering with an average case of malaria is lost. Accepting this as a basis, and including the loss through death, the cost of medicines, the losses to enterprises in malarious regions through the difficulty of securing competent labor, and other factors, it is safe to place the annual loss to the United States from malarial disease under present conditions at not less than one hundred millions of dollars. Celli has shown that in Italy the great railway industries, for example, feel the effect of malaria greatly. According to accurate calculations one company alone, for 1,400 kilometers of railway and for 6,416 workmen in malarious zones, spends on account of malaria 1,050,000 francs a year. The same writer states that the army in Italy from 1877 to 1897 had more than 300,000 cases of malaria.

The loss to this country in the way of retardation of the development of certain regions, owing to the presence of malaria, is extremely great. Certain territory containing most fertile soil and capable of the highest agricultural productiveness is practically abandoned. With the introduction of proper drainage measures and antimosquito work of other character, millions of acres of untold capacity could be released from the scourge at a comparatively slight expenditure. These regions in the absence of malaria would have added millions upon millions to the wealth of the country. Drainage measures are now being initiated by the United States. Parties of engineers are being sent by the Government to make preliminary drainage surveys in the most prominent of these potentially productive regions. The following statement concerning the effect of malaria on the progress of this work has been made to the writer by Dr. George Otis Smith, director of the United States Geological Survey:

"In one of the Southern States 11 topographic parties have been at work during the past field season. The full quota for these parties would be 55 men, but I believe that something over 100 men have been employed at different times during the season. While I have not exact figures before me, I feel warranted in the statement that at least 95 per cent of these employees have been sick, for periods ranging from a few days up to two weeks, in the hospital. Many of them have been able later to return to work, but at least 30 per cent had to leave the field permanently. By reason of this sickness the efficiency of the parties was reduced, at a very conservative estimate, by 25 per cent.

"In my recent visit in this field I found one man sick in each of the parties I saw and one man who had just returned from the hospital leaving the field for good. A similar state of things was reported from the other parties. I regard the sickness as practically all of a malarial nature, as extreme care was taken in all the camps to use nothing but boiled water except in a few instances where artesian water from great depths was available. In all the camps the tents have been screened, and in every case where the topographer has lived for any time 'on the country' there has been infection. As illustrating the value of the precautions generally taken by our camp parties, I might cite the fact that last year in West Virginia with 30 men living in camp, with typhoid fever prevalent in the neighborhood, no cases developed, while with 6 men living on the country where the same care could not be taken regarding the water supply, two cases of typhoid developed."

In estimating the weight of Doctor Smith's statement, it must be borne in mind that the men of his field parties are exceptionally intelligent and prepared to take all ordinary precautions.

Throughout the region in question malaria is practically universal. The railroads suffer, and at the stations throughout the territory it is practically impossible to keep operators steadily at work. This reduction in efficiency in the surveying parties and in the local railroad officials is moreover probably very considerably less than the reduction in the earning capacity of the entire population, which, however, is necessarily scanty.

In an excellent paper entitled "The relation of malaria to agricultural and other industries of the South," published in the Popular Science Monthly for April, 1903, Prof. Glenn W. Herrick, then of the College of Agriculture of Mississippi, after a consideration of the whole field, concludes that malaria is responsible for more sickness among the white population of the South than any disease to which it is now subject. The following forcible statement referring to the States of Louisiana, Mississippi, Alabama, Georgia, and South Carolina is in Professor Herrick's words:

"We must now consider briefly what 635,000 or a million cases of chills and fevers in one year mean. It is a self-evident truth that it means well for the physician. But for laboring men it means an immense loss of their time together with the doctors' fees in many instances. If members of their families other than themselves be affected, it may also mean a loss of time together with the doctors' fees. For the employer it means the loss of labor at a time perhaps when it would be of greatest value. If it does not mean the actual loss of labor to the employer it will mean a loss in the efficiency of his labor. To the farmers it may mean the loss of their crops by want of cultivation. It will always mean the noncultivation or imperfect cultivation of thousands of acres of valuable land. It means a listless activity in the world's work that counts mightily against the wealth-producing power of the people. Finally it means from two to five million or more days of sickness with all its attendant distress, pain of body, and mental depression to some unfortunate individuals of those five States."

Referring to the Delta region in Mississippi, which lies along the Mississippi River in the western part of the State of Mississippi, extending from the mouth of the Yazoo River north nearly to the Tennessee line, Herrick says that it is the second best farming land in the world, having only one rival, and that is the valley of the Nile. "Still," says Herrick, "this land to-day, or at least much of it, can be bought at ten to twenty dollars an acre. Thousands of acres in this region are still covered with the primeval forest, and the bears and deer still roaming there offer splendid opportunities for the chase, as evidenced by the late visit of our Chief Executive to those regions for the purpose of hunting. Why is not this land thickly settled? And why is it not worth from two to five hundred dollars an acre? If it produces from one to two or more bales of cotton to an acre, and it does, it ought to be worth the above named figures. A bale of cotton to the acre can be produced for thirteen dollars, leaving a net profit of twenty to forty dollars for each bale, or forty to eighty or more dollars for each acre of land cultivated. Moreover, this land has been doing that for years, and will do it for years to come, without the addition of one dollar's worth of fertilizer. Land that will produce a net profit of forty to eighty dollars an acre is a splendid investment at one, two, or even three hundred dollars an acre. Yet this land does not sell in the market for anything like so much, because the demand is not sufficient, for white people positively object to living in the Delta on account of malarial chills and fevers. A man said to me not long ago that he would go to the Delta that day if he were sure that his own life or the lives of the members of his family would not be shortened thereby. There are thousands exactly like him, and the only reason that these thousands do not go there to buy lands and make homes is on account of chills and fevers. But there is a time coming, and that not far distant, when malaria in the Delta will not menace the would-be inhabitants. When that time comes it will be the richest and most populous region in the United States."

Malaria is a preventable disease. It is possible for the human species to live and to thrive and to produce in malarious regions, but at a very considerable inconvenience and expense. The Italian investigators, and especially Celli and his staff, have shown that by screening the huts of the peasants on the Roman Campagna and by furnishing field laborers with veils and gloves when exposed to the night air, it is possible even in that famous hotbed of malaria to conduct farming operations with a minimum of trouble from the disease. Moreover, Koch and his assistants in German East Africa have shown that it is possible, by stamping out the disease among human beings by the free use of medicine, that a point can be gained where there is small opportunity for the malarial mosquitoes to become infected. Moreover, the work of the parties sent out by the Liverpool School of Tropical Medicine and other English organizations to the west coast of Africa has shown that by the treatment of malarial-mosquito breeding pools the pernicious coast fever may be greatly reduced. Again, the work of Englishmen in the Federated Malay States has shown that large areas may be practically freed from malaria. The most thorough and the most satisfactory of all measures consists in abolishing the breeding places of the malarial mosquitoes. In regions like the Delta of the Mississippi this involves extensive and systematic drainage, but in very many localities where the breeding places of the Anopheles mosquitoes can be easily eradicated, where they are readily located and are so circumscribed as to admit of easy treatment, it is possible to rid the section of malaria at a comparatively slight expense.

With a general popular appreciation of the industrial losses caused primarily by the malarial mosquito and secondarily by the forms which do not carry malaria, as indicated in the opening paragraphs, it is inconceivable that the comparatively inexpensive measures necessary should not be undertaken by the General Government, by the State governments, and by the boards of health of communities, just as it is inconceivable that the individual should suffer from malaria and from the attacks of other mosquitoes when he has individual preventives and remedies at hand. Large-scale drainage measures by the General Government involving large sections of valuable territory have been planned and are practically under way; certain States, notably New Jersey and New York, are beginning to work; communities all over the country through boards of health are also beginning to take notice, while popular education regarding the danger from mosquitoes and in regard to remedial measures is rapidly spreading. But all of this interest should be intensified, and the importance of the work should be displayed in the most emphatic manner, and relief from malaria and other mosquito conditions should be brought about as speedily as possible.

A few excellent examples of antimalarial work may be instanced:

The latest reports on the measures taken to abolish malaria from Klang and Port Swettenham in Selangor, Federated Malay States, indicate the most admirable results. These measures were undertaken first in 1901 and 1902, and have been reported upon from time to time in the Journal of Tropical Medicine. The expenditure undertaken by the Government with a view to improving the health of the inhabitants of these towns has been fully justified by the results, which promise to be of permanent value. The total expenditure for the town of Klang down to the end of 1905 was £3,100 ($15,086), and the annual permanent expenditure is about £60 ($292) for clearing earth drains and £210 ($1,022) for town gardeners. For Port Swettenham the total expenditure to the end of 1905 was £7,000 ($34,065), and the annual cost of keeping up the drains, etc., is approximately £40 ($195) for clearing earth drains, and £100 ($487) for town gardeners.

The careful tabulation of cases and deaths and of the results of the examination of blood of children in especially drained areas indicates the following conclusions: (1) Measures taken systematically to destroy breeding places of mosquitoes in these towns, the inhabitants of which suffered terribly from malaria, were followed almost immediately by a general improvement in health and decrease in death rate. (2) That this was due directly to the work carried out and not to a general dying out of malaria in the district is clearly shown by figures pointing out that while malaria has practically ceased to exist in the areas treated it has actually increased to a considerable extent in other parts of the district where antimalarial measures have not been undertaken.

The statistics for 1905 are even more favorable than those for 1902, which gives a very strong evidence in favor of the permanent nature of the improvement carried out. In fact it seems as though malaria has been permanently stamped out at Klang and Port Swettenham by work undertaken in 1901, and this experience in the Malay States should be of value to those responsible for the health of communities similarly situated in many other parts of the world.

Another striking example of excellent work of this kind is found in the recently published report on the suppression of malaria in Ismailia, issued under the auspices of the Compagnie Universelle du Canal Maritime de Suez. Ismailia is now a town of 8,000 inhabitants. It was founded by De Lesseps in April, 1862, on the borders of Lake Timsah, which the Suez Canal crosses at mid-distance between the Red Sea and the Mediterranean. Malarial fever made its appearance in very severe form in September, 1877, although the city had up to that time been very healthy, and increased so that since 1886 almost all of the inhabitants have suffered from the fever. In 1901 an attempt to control the disease was made on the mosquito basis, and this attempt rapidly and completely succeeded, and after two years of work all traces of malaria disappeared from the city. The work was directed not only against Anopheles mosquitoes, but against other culicids, and comprised the drainage of a large swamp and the other usual measures. The initial expense amounted to 50,000 francs ($9,650), and the annual expenses since have amounted to about 18,300 francs ($3,532).

The results may be summarized about as follows: Since the beginning of 1903 the ordinary mosquitoes have disappeared from Ismailia. Since the autumn of 1903 not a single larva of Anopheles has been found in the protected zone, which extends to the west for a distance of 1,000 meters from the first houses in the Arabian quarter and to the east for a distance of 1,800 meters from the first houses in the European quarter. After 1902 malarial fever obviously began to decrease, and since 1903 not a single new case of malaria has been found in Ismailia.

A very efficient piece of antimalarial work was accomplished in Havana during the American occupation of 1901 to 1902, incidental in a way to the work against yellow fever. An Anopheles brigade of workmen was organized under the sanitary officer, Doctor Gorgas, for work along the small streams, irrigated gardens, and similar places in the suburbs, and numbered from 50 to 300 men. No extensive drainage, such as would require engineering skill, was attempted, and the natural streams and gutters were simply cleared of obstructions and grass, while superficial ditches were made through the irrigated meadows. Among the suburban truck gardens Anopheles bred everywhere, in the little puddles of water, cow tracks, horse tracks, and similar depressions in grassy ground. Little or no oil was used by the Anopheles brigade, since it was found in practice a simple matter to drain these places. At the end of the year it was very difficult to find water containing mosquito larvæ anywhere in the suburbs, and the effect upon malarial statistics was striking. In 1900, the year before the beginning of the mosquito work, there were 325 deaths from malaria; in 1901, the first year of the mosquito work, 171 deaths; in 1902, the second year of mosquito work, 77 deaths. Since 1902 there has been a gradual though slower decrease, as follows: 1903, 51; 1904, 44; 1905, 32; 1906, 26; 1907, 23. These results, although less striking than those from Ismailia, involved a smaller expense in money and show surely an annual saving of 300 lives, and undoubtedly a corresponding decrease in the number of malarial cases, which may be estimated upon our earlier basis at something less than 40,000.

YELLOW FEVER.

Yellow fever has prevailed endemically throughout the West Indies and in certain regions on the Spanish Main virtually since the discovery of America. Barbados, Jamaica, and Cuba suffered epidemics before the middle of the seventeenth century. There were outbreaks in Philadelphia, Charleston, and Boston as early as 1692, and for a hundred years there were occasional outbreaks, culminating in the great Philadelphia epidemic of 1793. Northern cities were able, by rigid quarantine measures, to prevent great epidemics after the early part of the nineteenth century, but from the West Indies the disease was occasionally introduced and prevailed from time to time epidemically in the Southern States. In 1853 it raged throughout this region, New Orleans alone having a mortality of 8,000. The last widespread epidemic occurred in 1878, chiefly in Louisiana, Alabama, and Mississippi, but spreading up the Mississippi Valley as far as Cairo, Ill., and attacking with virulence the city of Memphis, Tenn. In this year there were 125,000 cases and 12,000 deaths. In 1882 there were 192 deaths at Pensacola; in 1887, 62 deaths in the Southern States; in 1893, 52 deaths; in 1897, 484; in 1898, 2,456 cases with 117 deaths; in 1903, 139 deaths were recorded, mostly at Laredo, Tex., and in 1905 there was a serious outbreak at New Orleans and in neighboring towns, including one locality in Mississippi, in which 911 deaths were recorded for the whole country.

The actual loss of life from yellow fever during all these years, when compared with the loss from other diseases, has been comparatively slight, but the death rate is perhaps the most insignificant feature of the devastation which yellow fever epidemics have produced, and the disease itself has been but a small part of the affliction which it has brought to the Southern States. The disease once discovered in epidemic form, the whole country has become alarmed; commerce in the affected region has come virtually to a standstill; cities have been practically deserted; people have died from exposure in camping out in the highlands; rigid quarantines have been established; innocent persons have been shot while trying to pass these quarantine lines; all industry for the time has ceased. The commerce of the South during the epidemic of 1878, for example, fell off 90 per cent, and the hardships of the population can not be estimated in monetary terms. With such industrial and commercial conditions existing from Texas to South Carolina, many industries at the North have suffered, and, in fact, the effect of a yellow fever summer in the South has been felt not only all over the United States, but in many other portions of the world.

All these conditions, as bad as they have been, do not sum up the total loss to the national prosperity during past years. Cities like Galveston, New Orleans, Mobile, Memphis, Jacksonville, and Charleston, subject to occasional epidemics, as they have been in the past, have not prospered as they should have done. Their progress has been greatly impeded by this one cause, and thus the industrial development of the entire South has been greatly retarded.

Physicians have been theorizing about the cause of yellow fever from the time when they began to treat it. It was thought by many that it was carried in the air; by others that it was conveyed by the clothing, bedding, or other articles which had come in contact with a yellow-fever patient. There were one or two early suggestions of the agency of mosquitoes, but practically no attention was paid to them, and they have been resurrected and considered significant only since the beginning of the present century. With the discovery of the agency of micro-organisms in the causation of disease, a search soon began for some causative germ. Many micro-organisms were found in the course of the autopsies, and many claims were put forth by investigators. All of these, however, were virtually set at rest by Sternberg in his "Report on the Etiology and Prevention of Yellow Fever," published in 1890, but a claim made by Sanarelli in June, 1897, for a bacillus which he called *Bacillus icteroides* received considerable credence, and in 1899 it was accepted in full by Wasden and Geddings, of the United States Marine-Hospital Service, who reported that they had found this bacillus in thirteen or fourteen cases of yellow fever in the city of Havana. There is no evidence, however, that this bacillus has anything to do with yellow fever. In 1881 Finlay, of Havana, proposed the theory that yellow fever, whatever its cause may be, is conveyed by means of *Culex* (now *Stegomyia*) *fasciatus* (now *calopus*). Subsequently he published several important papers, in which his views were modified from time to time, and in the course of which he mentioned experiments with 100 individuals, producing 3 cases of mild fever. None of the cases, however, was under his full control, and the possibility of other methods of contracting the disease was not excluded. Therefore, his theory, while it was received with interest, was not considered to be proved.

In 1890 came the beginning of the true demonstration. An army board was appointed by Surgeon-General Sternberg for the purpose of investigating the acute infectious diseases prevailing in the island of Cuba. The result achieved by this board, consisting of Reed, Carroll, Lazear, and Agramonte, was a demonstration that yellow fever is carried by *Stegomyia calopus*, and their ultimate demonstration was so perfect as to silence practically all expert opposition. The Third International Sanitary Convention of the American Republics unanimously accepted the conclusion that yellow fever is carried by this mosquito, and that the Stegomyia constitutes the only known means by which the disease is spread. To-day, after abundant additional demonstration, the original contention of Reed, Carroll, and Agramonte (Lazear having died in the course of the experiments) is a part of the accepted knowledge of the medical world. The importance of the discovery can not be overestimated, and its first demonstration was followed by antimosquito measures in the city of Havana, undertaken under the direction of Gorgas, with startling results.

Yellow fever had been endemic in Havana for more than one hundred and fifty years, and Havana was the principal source of infection for the rest of Cuba. Other towns in Cuba could have rid themselves of the disease if they had not been constantly reinfected from Havana. By ordinary sanitary measures of cleanliness, improved drainage, and similar means the death rate of the city was reduced, from 1898 to 1900, from 100 per thousand to 22 per thousand; but these measures had no effect upon yellow fever, this disease increasing as the nonimmune population following the Spanish war increased, and in 1900 there was a severe epidemic.

Stegomyia calopus was established as the carrier of the fever early in 1901, and then antimosquito measures were immediately begun. Against adult mosquitoes no general measures were attempted, although screening and fumigation were carried out in quarters occupied by yellow-fever patients or that had been occupied by yellow-fever patients. It was found that the Stegomyia bred principally in the rain-water collections in the city itself. The city was divided into about 30 districts, and to each district an inspector and two laborers were assigned, each district containing about a thousand houses. An order was issued by the mayor of Havana requiring all collections of water to be so covered that mosquitoes could not have access, a fine being imposed in cases where the order was not obeyed. The health department covered the rain-water barrels of poor families at public expense. All cesspools were treated with petroleum. All receptacles containing fresh water which did not comply with the law were emptied and on the second offense destroyed. The result of this work thoroughly done was to wipe out yellow fever in Havana, and there has not been a certain endemic case since that time.

In what is termed the New Orleans epidemic of 1905 a striking illustration of the value of this recently acquired mosquito-transmission knowledge is seen. The presence of yellow fever in the city was first recognized about the 1st of July, but it was the 12th of August before the Public Health and Marine-Hospital Service was put in complete control of the situation. By that time the increase in new cases and deaths rendered it practically certain that the disease was as widespread as during the terrible epidemic of 1878. There had been up to that date 142 deaths from a total of 913 cases, as against 152 deaths from a total of 519 cases in 1878. The Public Health and Marine-Hospital Service, under Doctor White, took hold of the situation with energy, basing its measures almost entirely upon a warfare against *Stegomyia calopus*. The disease began almost immediately to abate, and the result at the close of the season indicated 460 deaths, as against 4,046 in 1878, a virtual saving of over 3,500 lives. The following table of deaths from yellow fever in New Orleans from 1847 to 1905 points out most strikingly the value of this antimosquito work:

TABLE II.—*Comparative table of deaths from yellow fever in New Orleans during various years.*

Month.	Year.								
	1847.	1848.	1853.	1854.	1855.	1858.	1867.	1878.	1905.
May	....	....	2	....	....	....	....	....	....
June	....	4	31	2	5	2	3	....	....
July	71	33	1,521	29	382	132	11	26	35
August	965	200	5,133	532	1,286	1,140	255	1,025	236
September	1,100	467	982	1,234	874	2,204	1,637	1,780	107
October	198	126	147	490	97	1,137	1,072	1,065	59
November	12	20	28	131	19	224	103	147	23
December	10	....	4	7	7	15	26	3	....
Months unknown	445	22	....	....	....	....	....	....	....
Total	2,804	872	7,848	2,425	2,670	4,854	3,107	4,046	460

The epidemics of 1848, 1854, and 1855 are least comparable with that of 1905 because they immediately succeeded severe epidemics to which were due very many immunes.

The population of New Orleans by the United States Census was 130,565 in 1850; 168,675 in 1860; 191,418 in 1870; 216,090 in 1880, and 287,104 in 1900.

WORK ON THE ISTHMUS OF PANAMA.

The United States Government has very properly used the services of Colonel Gorgas, who was in charge of the eminently successful work at Havana, by appointing him chief sanitary officer of the Canal Zone during the digging of the canal. In 1904 active work was begun, and Colonel Gorgas was fortunate in having the services of Mr. Le Prince, who had been chief of his mosquito brigades in Havana, and therefore was perfectly familiar with antimosquito methods. In Panama, as in Havana, the population had depended principally upon rain water for domestic purposes, so that every house had cisterns, water barrels, and such receptacles for catching and storing rain water. The city was divided up into small districts with an inspector in charge of each district. This inspector was required to cover his territory at least twice a week and to make a report upon each building with regard to its condition as to breeding places of mosquitoes. All the cisterns, water barrels, and other water receptacles in Panama were covered as in Havana, and in the water barrels spigots were inserted so that the covers would not have to be taken off. Upon first inspection, in March, 4,000 breeding places were reported. At the end of October less than 400 containing larvæ were recorded. This gives one a fair idea of the consequent rapid decrease in the number of mosquitoes in the city. These operations were directed primarily against the yellow-fever mosquito, and incidentally against the other common species that inhabit rain-water barrels. Against the Anopheles in the suburbs the same kind of work was done as was done in Havana, with exceptionally good results.

The same operations were carried on in the villages between Panama and Colon. There are some twenty of these villages, running from 500 to 3,000 inhabitants each. Not a single instance of failure has occurred in the disinfection of these small towns, and the result of the whole work has been the apparent elimination of yellow fever and the very great reduction of malarial fever.

The remarkable character of these results can only be judged accurately by comparative methods. It is well known that during the French occupation there was an enormous mortality among the European employees, and this was a vital factor in the failure of the work. Exact losses can not be estimated, since the work was done under 17 different contractors. These contractors were charged $1 a day for every sick man to be taken care of in the hospital of the company. Therefore it often happened that when a man became sick his employer discharged him, so that he would not have to bear the expense of hospital charges. There was no police patrol of the territory and many of these men died along the line. Colonel Gorgas has stated that the English consul, who was at the Isthmus during the period of the French occupation, is inclined to think that more deaths of employees occurred out of the hospital than in it. A great many were found to have died along the roadside while endeavoring to find their way to the city of Panama. The old superintendent of the French hospital states that one day 3 of the medical staff died from yellow fever, and in the same month 9 of the medical staff. Thirty-six Roman Catholic sisters were brought over as nurses, and 24 died of yellow fever. On one vessel 18 young French engineers came over, and in a month after their arrival all but one died.

Now that the relation of the mosquito to yellow fever is well understood, it was found during the first two years under Doctor Gorgas that, although there were constantly one or more yellow-fever cases in the hospital, and although the nurses and physicians were all non-immunes, not a single case of yellow fever was contracted in that way. The nurses never seemed to consider that they were running any risk in attending yellow fever cases night and day in screened wards, and the wives and families of officers connected with the hospital lived about the grounds, knowing that yellow fever was constantly being brought into the grounds and treated in near-by buildings. Americans, sick from any cause, had no fear when being treated in beds immediately adjoining those of yellow-fever patients. Colonel Gorgas and Doctor Carter lived in the old ward used by the French for their officers, and Colonel Gorgas thinks it safe to say that more men had died from yellow fever in that building under the French régime than in any other building of the same capacity at present standing. He and Doctor Carter had their wives and children with them, which would formerly have been considered the height of recklessness, but they looked upon themselves, under the now recognized precautions, as being as safe, almost, as they would have been in Philadelphia or Boston.

No figures of the actual cost of the antimosquito work, either in Havana or in the Panama Canal Zone, are accessible to the writer, but it is safe to say that it was not exorbitant, and that it was not beyond the means of any well-to-do community in tropical regions.

THE TYPHOID FLY, COMMONLY KNOWN AS THE HOUSE FLY.

The name "typhoid fly" is here proposed as a substitute for the name "house fly," now in general use. People have altogether too long considered the house fly as a harmless creature, or, at the most, simply a nuisance. While scientific researches have shown that it is a most dangerous creature from the standpoint of disease, and while popular opinion is rapidly being educated to the same point, the retention of the name house fly is considered inadvisable, as perpetuating in some degree the old ideas. Strictly speaking, the term "typhoid fly" is open to some objection, as conveying the erroneous idea that this fly is solely responsible for the spread of typhoid, but considering that the creature is dangerous from every point of view, and that it is an important element in the spread of typhoid, it seems advisable to give it a name which is almost wholly justified and which conveys in itself the idea of serious disease. Another repulsive name that might be given to it is "manure fly," but recent researches have shown that it is not confined to manure as a breeding place, although perhaps the great majority of these flies are born in horse manure. For the end in view, "typhoid fly" is considered the best name.

The true connection of the so-called house fly with typhoid fever and the true scientific evidence regarding its rôle as a carrier of that disease have only recently been worked out. Celli in 1888 fed flies with pure cultures of the typhoid bacillus, and examined their contents and dejections microscopically and culturally. Inoculations of animals were also made, proving that the bacilli which passed through flies were virulent. Dr. George M. Kober, familiar with Celli's researches, in his report on the prevalence of typhoid fever in the District of Columbia, published in 1895, called especial attention to the danger of the contamination of food supplies by flies coming from the excreta of typhoid patients. The prevalence of typhoid fever in the concentration camps of the United States Army in the summer of 1898 brought about the appointment of an army typhoid commission consisting of Drs. Walter Reed, U. S. Army, Victor M. Vaughan, U. S. Volunteers, and E. O. Shakespeare, U. S. Volunteers. A paper read by Doctor Vaughan before the annual meeting of the American Medical Association at Atlantic City, N. J., June 6, 1900, contained the following conclusions with regard to flies:

"27. *Flies undoubtedly served as carriers of the infection.*

"My reasons for believing that flies were active in the dissemination of typhoid may be stated as follows:

"*a.* Flies swarmed over infected fecal matter in the pits and then visited and fed upon the food prepared for the soldiers at the mess tents. In some instances where lime had recently been sprinkled over the contents of the pits, flies with their feet whitened with lime were seen walking over the food.

"*b.* Officers whose mess tents were protected by means of screens suffered proportionately less from typhoid fever than did those whose tents were not so protected.

"*c.* Typhoid fever gradually disappeared in the fall of 1898, with the approach of cold weather, and the consequent disabling of the fly.

"It is possible for the fly to carry the typhoid bacillus in two ways. In the first place, fecal matter containing the typhoid germ may adhere to the fly and be mechanically transported. In the second place, it is possible that the typhoid bacillus may be carried in the digestive organs of the fly and may be deposited with its excrement."

There were also many important conclusions which bear upon the fly question. For example, it was shown that every regiment in the United States service in 1898 developed typhoid fever, nearly all of them within eight weeks after assembling in camps. It not only appeared in every regiment in the service, but it became epidemic both in small encampments of not more than one regiment and in the larger ones consisting of one or more corps. All encampments located in the Northern as well as in the Southern States exhibited typhoid in epidemic form. The miasmatic theory of the origin of typhoid fever and the pythogenic theory[a] were not supported by the investigations of the commission, but the doctrine of the specific

[a] This theory is founded upon the belief that the colon germ may undergo a ripening process by means of which its virulence is so increased and altered that it may be converted into the typhoid bacillus or at least may become the active agent in the causation of typhoid fever.

origin of the fever was confirmed. The conclusion was reached that the fever is disseminated by the transference of the excretions of an infected individual to the alimentary canals of others, and that a man infected with typhoid fever may scatter the infection in every latrine or regiment before the disease is recognized in himself, while germs may be found in the excrement for a long time after the apparently complete recovery of the patient. Infected water was not an important factor in the spread of typhoid in the national encampments of 1898, but about one-fifth of the soldiers in the national encampments in the United States during that summer developed this disease, while more than 80 per cent of the total deaths were caused by typhoid.

In 1899 the writer began the study of the typhoid or house fly under both country and city conditions. He made a rather thorough investigation of the insect fauna of human excrement, and made a further investigation of the species of insects that are attracted to food supplies in houses. In a paper entitled "A Contribution to the Study of the Insect Fauna of Human Excrement (with special reference to the spread of typhoid fever by flies)," published in the Proceedings of the Washington Academy of Sciences, Volume II, pages 541-604, December 28, 1900, he showed that 98.8 per cent of the whole number of insects captured in houses throughout the whole country under the conditions indicated above were *Musca domestica*, the typhoid or house fly. He showed further that this fly, while breeding most numerously in horse stables, is also attracted to human excrement and will breed in this substance. It was shown that in towns where the box privy was still in existence the house fly is attracted to the excrement, and, further, that it is so attracted in the filthy regions of a city where sanitary supervision is lax and where in low alleys and corners and in vacant lots excrement is deposited by dirty people. He stated that he had seen excrement which had been deposited overnight in an alleyway in South Washington swarming with flies under the bright sunlight of a June morning (temperature 92° F.), and that within 30 feet of these deposits were the open windows and doors of the kitchens of two houses kept by poor people, these two houses being only elements in a long row. The following paragraph is quoted from the paper just cited:

"Now, when we consider the prevalence of typhoid fever and that virulent typhoid bacilli may occur in the excrement of an individual for some time before the disease is recognized in him, and that the same virulent germs may be found in the excrement for a long time after the apparent recovery of a patient, the wonder is not that typhoid is so prevalent but that it does not prevail to a much greater extent. Box privies should be abolished in every community. The depositing of excrement in the open within town or city limits should be considered a punishable misdemeanor in communities which have not already such regulations, and it should be enforced more rigorously in towns in which it is already a rule. Such offenses are generally committed after dark, and it is often difficult or even impossible to trace the offender; therefore, the regulation should be carried even further and require the first responsible person who notices the deposit to immediately inform the police, so that it may be removed or covered up. Dead animals are so reported; but human excrement is much more dangerous. Boards of health in all communities should look after the proper treatment or disposal of horse manure, primarily in order to reduce the number of house flies to a minimum, and all regulations regarding the disposal of garbage and foul matter should be made more stringent and should be more stringently enforced."

In the opening sentence of the paragraph just quoted attention was called to the activity of bacilli in excreta passed by individuals after apparent recovery from typhoid. Since the paper in question was published, more especial attention has been drawn by medical men to this point, and it has been shown that individuals who are chronic spreaders of the typhoid germs are much more abundant than was formerly supposed. Dr. George A. Soper recently discovered a striking case of this kind in the person of a cook employed successively by several families in the vicinity of New York City, with the result that several cases of typhoid occurred in each of these families. In a paper by Doctor Davids and Professor Walker, read before the Royal Sanitary Institute of London during the present season, the history was given of four personal carriers of typhoid who had communicated the disease to a number of people. These four carriers were detected in one city within a few months, and from this fact it can be argued with justice that such cases are comparatively numerous. This being true, the presence of unguarded miscellaneous human excreta deposited in city suburbs, in vacant lots, and in low alleyways intensifies to a very marked degree the danger that the food will become contaminated with typhoid bacilli by means of the typhoid or house fly. It is known, too, that the urine of persons who have suffered from typhoid fever often contains active typhoid bacilli for several weeks after the patients have recovered; consequently this also is a source of danger.

The importance of the typhoid fly as a carrier of the disease in army camps, as shown in the Spanish war and in the Boer war and in the camps of great armies of laborers engaged in gigantic enterprises like the digging of the Panama canal, is obvious, but what has just been stated indicates that even under city conditions the influence of this fly in the spread of this disease has been greatly underestimated. It is not claimed that under city conditions the house fly becomes by this argument a prime factor in the transfer of the disease, but it must obviously take a much higher relative rank among typhoid conveyers than it has hitherto assumed. Perhaps even under city conditions it must assume third rank—next to water and milk.

It is not alone as a carrier of typhoid that this fly is to be feared. In the same way it may carry nearly all the intestinal diseases. It is a prime agent in the spreading of summer dysentery, and in this way is unquestionably responsible for the death of many children in summer. One of the earliest accurate scientific studies of the agency of insects in the transfer of human disease was in regard to flies as spreaders of cholera. The belief in this agency long preceded its actual proof. Dr. G. E. Nicholas, in the London Lancet, Volume II, 1873, page 724, is quoted by Nuttall as writing as follows regarding the cholera prevailing at Malta in 1849: "My first impression of the possibility of the transfer of the disease by flies was derived from the observation of the manner in which these voracious creatures, present in great numbers, and having equal access to the dejections and food of patients, gorged themselves indiscriminately and then disgorged themselves on the food and drinking utensils. In 1850 the *Superb*, in common with the rest of the Mediterranean squadron, was at sea for nearly six months; during the greater part of the time she had cholera on board. On putting to sea, the flies were in great force; but after a time the flies gradually disappeared, and the epidemic slowly subsided. On going into Malta Harbor, but without communicating with the shore, the flies returned in greater force, and the cholera also with increased violence. After more cruising at sea, the flies disappeared gradually with the subsidence of the disease."

Accurate scientific bacteriological observations by Tizzoni and Cattani in 1886 showed definitely active cholera organisms in the dejecta of flies caught in the cholera wards in Bologna, Italy. These observations were subsequently verified and extended by Simonds, Offelmann, Macrae, and others.

With tropical dysentery and other enteric diseases practically the same conditions exist. In a report by Daniel D. Jackson to the committee on pollution, of the Merchants' Association in New York, published in December, 1907, the results of numerous observations upon the relation of flies to intestinal diseases are published, and the relation of deaths from intestinal diseases in New York City to the activity and prevalence of the common house fly is shown not only by repeated observations but also by an interesting plotting of the curve of abundance of flies in comparison with the plotted curve of abundance of deaths from intestinal diseases, indicating that the greatest number of flies occurred in the weeks ending July 27 and August 3; also, that the deaths from intestinal diseases rose above the normal at the same time at which flies became prevalent, culminated at the same high point, and fell off with slight lag at the time of the gradual falling off of the prevalence of the insects.

Similar studies have been carried on during the summer of 1908 in the city of Washington, and the curve of typhoid-fly abundance for the whole city, as well as that for a district comprising eight city squares in which intensive studies have been made both of flies and of disease, will be plotted at the close of the season. At the time of present writing this work has not been completed.

The typhoid fly also possesses importance as a disseminator of the bacilli of tuberculosis. In a paper by Dr. Frederick T. Lord, of Boston, reprinted from the Boston Medical and Surgical Journal for December 15, 1904, pages 651–654, the following conclusions are reached:

"1. Flies may ingest tubercular sputum and excrete tubercle bacilli, the virulence of which may last for at least fifteen days.

"2. The danger of human infection from tubercular flyspecks is by the ingestion of the specks on food. Spontaneous liberation of tubercle bacilli from flyspecks is unlikely. If mechanically disturbed, infection of the surrounding air may occur.

"As a corollary to these conclusions, it is suggested that—

"3. Tubercular material (sputum, pus from discharging sinuses, fecal matter from patients with intestinal tuberculosis, etc.) should be carefully protected from flies, lest they act as disseminators of the tubercle bacilli.

"4. During the fly season greater attention should be paid to the screening of rooms and hospital wards containing patients with tuberculosis and laboratories where tubercular material is examined.

"5. As these precautions would not eliminate fly infection by patients at large, foodstuffs should be protected from flies which may already have ingested tubercular material."

From all these facts it appears that the most important part played by the typhoid fly or house fly in the human economy is to carry bacteria from one place to another. The following table and comments are taken from Bulletin No. 51 (April, 1908), of the Storrs Agricultural Experiment Station, Storrs, Conn., entitled "Sources of Bacteria in Milk," by W. M. Esten and C. J. Mason:

TABLE III.—*Sources of bacteria from flies.*

Date.	Source.	Total number.	Total acid bacteria.	Rapid liquefying bacteria.	Slow liquefying bacteria.	*Bacterium lactis acidi.* Group A. Class 1.	*Coli-ærogenes.* Group A. Class 2.
1907.							
July 27	(*a*) 1 fly, bacteriological laboratory	3,150	250	600	100		
July 27	(*b*) 1 fly, bacteriological laboratory	550	100	0	0		
Aug. 6	(*c*) 19 cow-stable flies	7,980,000	220,000	0	20,000		
	Average per fly	420,000	11,600	0	1,000		
Aug. 14	(*d*) 94 swill-barrel flies	155,000,000	8,950,000	0	0	4,320,000	4,630,000
	Average per fly	1,660,000	95,300	0	0	46,000	49,300
Aug. 14	(*e*) 144 pigpen flies	133,000,000	2,110,000	100,000	266,000	933,000	1,176,000
	Average per fly	923,000	18,700	700	1,150	6,500	12,200
Sept. 4	(*f*) 18 swill-barrel flies	118,800,000	40,480,000	0	14,500,000	10,480,000	30,000,000
	Average per fly	6,600,000	2,182,000	0	804,000	582,000	1,600,000
Sept. 21	(*g*) 30 dwelling-house flies	1,425,000	125,000	0	12,500		
	Average per fly	47,580	4,167	0	417		
Sept. 21	(*h*) 26 dwelling-house flies	22,880,000	22,596,000	120,000	34,000		
	Average per fly	880,000	869,000	4,600	1,300		
Sept. 27	(*i*) 110 dwelling-house flies	35,500,000	13,670,000	8,840,000	125,000		
	Average per fly	322,700	124,200	80,300	1,100		
Aug. 20	(*j*) 1 large bluebottle blowfly	308,700	(*a*)				
	Total average of 414 flies	1,222,570	367,300	7,830	73,500		
	Average per cent of 414 flies		30	6	6		
	Average per fly of 256 flies, experiments (*d*), (*e*), and (*f*)	3,061,000	765,000	230	268,700	211,500	553,800
	Average per cent of 256 flies, experiments (*d*), (*e*), and (*f*)		25		8	7	18

[a] 2,200 mold spores.

"From the above table the bacterial population of 414 flies is pretty well represented. The domestic fly is passing from a disgusting nuisance and troublesome pest to a reputation of being a dangerous enemy to human health. A species of mosquito has been demonstrated to be the cause of the spread of malaria. Another kind of mosquito is the cause of yellow fever, and now the house fly is considered an agency in the distribution of typhoid fever, summer complaint, cholera infantum, etc.

"The numbers of bacteria on a single fly may range all the way from 550 to 6,600,000. Early in the fly season the numbers of bacteria on flies are comparatively small, while later the numbers are comparatively very large. The place where flies live also determines largely the numbers that they carry. The average for the 414 flies was about one and one-fourth million bacteria on each. It hardly seems possible for so small a bit of life to carry so large a number of organisms. The method of the experiment was to catch the flies from the several sources by means of a sterile fly net, introduce them into a sterile bottle, and pour into the bottle a known quantity of sterilized water, then shake the bottle to wash the bacteria from their bodies, to simulate the number of organisms that would come from a fly in falling into a lot of milk. In experiments '*d*,' '*e*,' and '*f*' the bacteria were analyzed into four groups. The objectionable class, *coli-aerogenes* type, was two and one-half times as abundant as the favorable acid type. If these flies stayed in the pigpen vicinity there would be less objection to the flies and the kinds of organisms they carry, but the fly is a migratory insect and it visits everything 'under the sun.' It is almost impossible to keep it out of our kitchens, dining rooms, cow stables, and milk rooms. The only remedy for this rather serious condition of things is, remove the pigpen as far as possible from the dairy and dwelling house. Extreme care should be taken in keeping flies out of the cow stable, milk rooms, and dwellings. Flies walking over our food are the cause of one of the worst contaminations that could occur from the standpoint of cleanliness and the danger of distributing disease germs."

The danger of the typhoid or house fly in the carriage of disease has thus been abundantly demonstrated. Further than this, it is an intolerable nuisance. With mosquitoes it necessitates an annual outlay for window and door screens in the United States of not less than ten millions of dollars. As a carrier of disease it causes a loss of many millions of dollars annually. Dr. G. N. Kober, in a paper prepared for the Governors' Conference on the Conservation of Natural Resources, held at the White House in May, 1908, entitled "The Conservation of Life and Health by Improved Water Supply," presented figures showing that the decrease in the vital assets of the country through typhoid fever in a single year is more than $350,000,000. The house fly, as an important agent in the spread of this disease, is responsible for a very considerable portion of this decrease in vital assets. As an agency in the spread of other intestinal diseases, this sum must be greatly increased, and yet it is allowed to breed unrestricted all over the United States; it is allowed to enter freely the houses of the great majority of our people; it is allowed to spread bacteria freely over our food supplies in the markets and in the kitchens and dining rooms of private houses, and, to use the happy phraseology of Dr. Theobald Smith, "when we go into public restaurants in midsummer we are compelled to fight for our food with the myriads of house flies which we find there alert, persistent, and invincible."

Even if the typhoid or house fly were a creature difficult to destroy, the general failure on the part of communities to make any efforts whatever to reduce its numbers could properly be termed criminal neglect; but since, as will be shown, it is comparatively an easy matter to do away with the plague of flies, this neglect becomes an evidence of ignorance or of a carelessness in regard to disease-producing filth which to the informed mind constitutes a serious blot on civilized methods of life.

Strange as it may seem, an exhaustive study of the conditions which produce house flies in numbers has never been made. The life history of the insect in general was, down to 1873, mentioned in only three European works and few exact facts were given. In 1873 Dr. A. S. Packard, then of Salem, Mass., studied the transformations of the insect and gave descriptions of all stages, showing that the growth of a generation from the egg state to the adult occupies from 10 to 14 days.

In 1895 the writer traced the life history in question, indicating that 120 eggs are laid by a single female, and that in Washington, in midsummer, a generation is produced every 10 days. Although numerous substances were experimented with, he was able to breed the fly only in horse manure. Later investigations indicated that the fly will breed in human excrement and in other fermenting vegetable and animal material, but that the vast majority of the flies that infest dwelling houses, both in cities and on farms, come from horse manure.

In 1907 careful investigations carried on in the city of Liverpool by Robert Newstead, lecturer in economic entomology and parasitology in the School of Tropical Medicine of the University of Liverpool, indicated that the chief breeding places of the house fly in that city should be classified under the following heads:

(1) Middensteads (places where dung is stored) containing horse manure only.

(2) Middensteads containing spent hops.

(3) Ash pits containing fermenting materials.

He found that the dung heaps of stables containing horse manure only were the chief breeding places. Where horse and cow manures were mixed the flies bred less numerously, and in barnyards where fowls were kept and allowed freedom relatively few of the house flies were found. Only one midden containing warm spent hops was inspected, and this was found to be as badly infested as any of the stable middens. A great deal of time was given to the inspection of ash pits, and it was found that wherever fermentation had taken place and artificial heat had been thus produced, such places were infested with house-fly larvæ and pupæ, often to the same alarming extent as in stable manure. Such ash pits as these almost invariably contained large quantities of old bedding or straw and paper, paper mixed with human excreta, or old rags, manure from rabbit hutches, etc., or a mixture of all these. About 25 per cent of the ash pits examined were thus infested, and house flies were found breeding in smaller numbers in ash pits in which no heat had been engendered by fermentation. The house fly was also found breeding by Mr. Newstead in certain temporary breeding places, such as collections of fermenting vegetable refuse, accumulations of manure at the wharves, and in bedding in poultry pens.

Still more recent investigations were carried on during 1908 by Prof. S. A. Forbes, State entomologist of Illinois, who has reared it in large numbers from the contents of paunches of slaughtered cattle, from refuse hog hairs, from tallow vats, from carcasses of various animals, miscellaneous garbage, and so on.

All this means that if we allow the accumulation of filth we will have house flies, and if we do not allow it to accumulate we will have no house flies. With the careful collection of garbage in cans and the removal of the contents at more frequent intervals than 10 days, and with the proper regulation of abattoirs, and more particularly with the proper regulation of stables in which horses are kept, the typhoid fly will become a rare species. It will not be necessary to treat horse manure with chlorid of lime or with kerosene or with a solution of Paris green or arsenate of lead, if stable men are required to place the manure daily in a properly covered receptacle and if it is carried away once a week.

The orders of the health department of the District of Columbia, published May 3, 1906, if carried out will be very effective. These orders may be briefly condensed as follows:

All stalls in which animals are kept shall have the surface of the ground covered with a water-tight floor. Every person occupying a building where domestic animals are kept shall maintain, in connection therewith, a bin or pit for the reception of manure, and pending the removal from the premises of the manure from the animal or animals shall place such manure in said bin or pit. This bin shall be so constructed as to exclude rain water, and shall in all other respects be water-tight, except as it may be connected with the public sewer. It shall be provided with a suitable cover and constructed so as to prevent the ingress and egress of flies. No person owning a stable shall keep any manure or permit any manure to be kept in or upon any portion of the premises other than the bin or pit described, nor shall he allow any such bin or pit to be overfilled or needlessly uncovered. Horse manure may be kept tightly rammed into well-covered barrels for the purpose of removal in such barrels. Every person keeping manure in any of the more densely populated parts of the District shall cause all such manure to be removed from the premises at least twice every week between June 1 and October 31, and at least once every week between November 1 and May 31 of the following year. No person shall remove or transport any manure over any public highway in any of the more densely populated parts of the District except in a tight vehicle, which, if not inclosed, must be effectually covered with canvas, so as to prevent the manure from being dropped. No person shall deposit manure removed from the bins or pits within any of the more densely populated parts of the District without a permit from the health officer. Any person violating any of these provisions shall, upon conviction thereof, be punished by a fine of not more than $40 for each offense.

In addition to this excellent ordinance, others have been issued from the health department of the District of Columbia which provide against the contamination of exposed food by flies and by dust. The ordinances are excellently worded so as to cover all possible cases. They provide for the registration of all stores, markets, cafés, lunch rooms, or of any other place where food or beverage is manufactured or prepared for sale, stored for sale, offered for sale, or sold, in order to facilitate inspection, and still more recent ordinances provide for the registration of stables. An excellent campaign was begun during the summer of 1908 against insanitary lunch rooms and restaurants. A number of cases were prosecuted, but conviction was found to be difficult.

For one reason or another, the chief reason being the lack of a sufficient force of inspectors under the control of the health officers, the ordinance in regard to stables has not been carried out with that perfection which the situation demands. In the summer of 1896, the health officer of the District, Dr. W. C. Woodward, designated a region in Washington bounded by Pennsylvania avenue, Sixth street, Fifteenth street, and the Potomac River, which was to be watched by assistants of the writer. Twenty-four stables were located in this region and were visited weekly by two assistants chosen for the purpose. The result was that on the whole the manure was well looked after and the number of flies in the region in question was very considerably reduced during the time of inspection.

Were simple inspection of stables all that is needed, a force of four inspectors, specially detailed for this work, could cover the District of Columbia, examining every stable, after they were once located and mapped, once a week. The average salary of an inspector is $1,147, so that the total expense for the first year would be something like $4,500. But the inspectors' service is complicated by the matter of prosecution. Much of the time of inspectors would be taken in the prosecution of the owners of neglected premises. Moreover, the health officer has found during the summer of 1908, in his prosecution of the owners or managers of insanitary restaurants, that his inspectors were practically sworn out of court by the multiplicity of opposing evidence. This means that it will be necessary in such cases to send two inspectors together in all cases, so that the testimony of one may be supported by the testimony of the other. This, perhaps, would double the number of necessary inspectors, making the expense of the service something over $9,000. It is reasonably safe to state, however, that with such an expense for competent service, or perhaps with a slightly added expense, the typhoid fly could be largely eliminated as an element in the transfer of disease in the District of Columbia, and the difficulty which the authorities have had in locating the cause of a very considerable proportion of the cases of typhoid in the District for the past two or three years indicates plainly to the mind of the writer that the typhoid fly is a much more important element than has been supposed. It is a comforting although comparatively insignificant fact and a matter of common observation that in certain sections of the city the typhoid fly has been much less numerous during the past summer than in previous years. The writer is inclined to attribute this to the gradual disappearance of horse stables in such sections, brought about by the rapidly increasing use of motor vehicles.

A significant paragraph in Mr. Newstead's Liverpool report, referred to above, contains the following words: "The most strenuous efforts should be made to prevent children defecating in the courts and passages; or that the parents should be compelled to remove such matter immediately; and that defecation in stable middens should be strictly forbidden. The danger lies in the overwhelming attraction which such fecal matter has for house flies, which later may come into direct contact with man or his foodstuffs. They may, as Veeder puts it, 'In a very few minutes * * * load themselves with dejections from a typhoid or dysenteric patient, not as yet sick enough to be in hospital or under observation, and carry the poison so taken up into the very midst of the food and water ready for use at the next meal. There is no long, roundabout process involved.'"

The writer has already referred to this general subject in his remarks on the depositing of excrement in the open within town or city limits, but Newstead's specific reference to children reminds one that in the tenement districts of the older great cities of England and other parts of Europe there occur opportunities for transfer of disease which, while probably less numerous in the newer cities of the United States, nevertheless must still exist and be a constant danger.

We have thus shown that the typhoid or house fly is a general and common carrier of pathogenic bacteria. It may carry typhoid fever, Asiatic cholera, dysentery, cholera morbus, and other intestinal diseases; it may carry the bacilli of tuberculosis and certain eye diseases; it is everywhere present, and it is disposed of with comparative ease. It is the duty of every individual to guard so far as possible against the occurrence of flies upon his premises. It is the duty of every community, through its board of health, to spend money in the warfare against this enemy of mankind. This duty is as pronounced as though the community were attacked by bands of ravenous wolves.

As a matter of fact, large sums of money are spent annually in the protection of property in the United States. Large sums of money are spent also in health matters; but the expenditure for protection from flies is very small and is misdirected. There is much justification for the following criticism published editorially in the Journal of the American Medical Association for August 22, 1908, under the caption, "National Farm Commission and Rural Sanitation:"

"The President calls attention to the fact that all efforts to aid the farmers have hitherto been directed to improving their material welfare, while the man himself and his family have been neglected. Nowhere is this more marked than in the attitude of the General Government in matters relating to sanitation. It is a trite saying that whereas the Government, through the Department of Agriculture, aids the farmer generously in caring for the health of his hogs, sheep, etc., it does nothing for his own health. The Government issues notices to the farmer of the injury done to his crops by the cotton-boll weevil and the potato bugs and how to combat them, but the injury the mosquito does in spreading malaria to the people who pick the cotton and hoe the potatoes is not impressed on him. The fact that horseflies may carry anthrax to his cattle is dealt with at considerable length, but the diseases which the house fly spreads to the milk and to the farmer's family attract practically no attention. How to build a hogpen or a sanitary barn is the subject of a number of government publications, but how to build a sanitary privy which will prevent the spread of typhoid, hook worm, and many other diseases is regarded as of strictly local interest."

But this criticism is not entirely justified, since there was published by the Bureau of Entomology of the United States Department of Agriculture, in 1900, a Farmers' Bulletin, entitled "How Insects Affect Health in Rural Districts,"[a] in which all of these points mentioned by the editor of the Journal of the American Medical Association have been touched upon, and at the date of present writing 192,000 copies of this bulletin have been distributed among the people. Moreover, a number of years ago a circular[b] was published on the subject of the house fly, calling attention to its dangers and giving instructions such as are covered in a general way in this article, and some 18,000 copies of this circular have also been distributed. This is an indication that the General Government is by no means blind to the people's needs in such matters as we have under consideration, but further work should be done. That the English Government is awaking to the same need is shown by the fact that, in the parliamentary vote of the present year in aid of

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[a] Farmers' Bulletin No. 155.

[b] Circular No. 35, Bureau of Entomology, 1891, afterwards reissued in revised form as Circular No. 71.

scientific investigations concerning disease, one of the projects supported by the General Government was the investigation of Doctors Copeman and Nuttall on flies as carriers of disease.

A leading editorial in an afternoon paper of the city of Washington, of October 20, 1908, bears the heading, "Typhoid a National Scourge," arguing that it is to-day as great a scourge as tuberculosis. The editorial writer might equally well have used the heading "Typhoid a National Reproach," or perhaps even "Typhoid a National Crime," since it is an absolutely preventable disease. And as for the typhoid fly, that a creature born in indescribable filth and absolutely swarming with disease germs should practically be invited to multiply unchecked, even in great centers of population, is surely nothing less than criminal.

ENDEMIC DISEASE AS AFFECTING THE PROGRESS OF NATIONS.

In referring to the spread of malaria in Greece, the relation of this disease to the rise and fall of national power has been touched upon in an earlier paragraph of this bulletin (p. 9). The subject is one of the widest importance and deserves a more extended consideration.

The following paragraphs are quoted from Ronald Ross's address on Malaria in Greece, delivered before the Oxford Medical Society, November 29, 1906:

"Now, what must be the effect of this ubiquitous and everlasting incubus of disease on the people of modern Greece? Remember that the malady is essentially one of infancy among the native population. Infecting the child one or two years after birth, it persecutes him until puberty with a long succession of febrile attacks, accompanied by much splenomegaly and anæmia. Imagine the effect it would produce upon our own children here in Britain. It is true that our children suffer from many complaints—scarlatina, measles, whooping cough—but these are of brief duration and transient. But now add to these, in imagination, a malady which lasts for years, and may sometimes attack every child in a village. What would be the effect upon our population—especially our rural population—upon their numbers and upon the health and vigour of the survivors? It must be enormous in Greece. People often seem to think that such a plague strengthens a race by killing off the weaker individuals; but this view rests upon the unproven assumption that it is really the weaker children which can not survive. On the contrary, experience seems to show that it is the stronger blood which suffers most—the fair, northern blood which nature attempts constantly to pour into the southern lands. If this be true, the effect of malaria will be constantly to resist the invigorating influx which nature has provided; and there are many facts in the history of India, Italy, and Africa which could be brought forward in support of this hypothesis.

"We now come face to face with that profoundly interesting subject, the political, economical, and historical significance of this great disease. We know that malaria must have existed in Greece ever since the time of Hippocrates, about 400 B. C. What effect has it had on the life of the country? In prehistoric times Greece was certainly peopled by successive waves of Aryan invaders from the north—probably a fair-haired people—who made it what it became, who conquered Persia and Egypt, and who created the sciences, arts, and philosophies which we are only developing further to-day. That race reached its climax of development at the time of Pericles. Those great and beautiful valleys were thickly peopled by a civilization which in some ways has not been excelled. Everywhere there were cities, temples, oracles, arts, philosophies, and a population vigorous and well trained in arms. Lake Kopais, now almost deserted, was surrounded by towns whose massive works remain to this day. Suddenly, however, a blight fell over all. Was it due to internecine conflict or to foreign conquest? Scarcely; for history shows that war burns and ravages, but does not annihilate. Thebes was thrice destroyed, but thrice rebuilt. Or was it due to some cause, entering furtively and gradually sapping away the energies of the race by attacking the rural population, by slaying the new-born infant, by seizing the rising generation, and especially by killing out the fair-haired descendant of the original settlers, leaving behind chiefly the more immunised and darker children of their captives, won by the sword from Asia and Africa? * * *

"I can not imagine Lake Kopais, in its present highly malarious condition, to have been thickly peopled by a vigorous race; nor, on looking at those wonderful figured tombstones at Athens, can I imagine that the healthy and powerful people represented upon them could have ever passed through the anæmic and splenomegalous infancy (to coin a word) caused by widespread malaria. Well, I venture only to suggest the hypothesis, and must leave it to scholars for confirmation or rejection. Of one thing I am confident, that causes such as malaria, dysentery, and intestinal entozoa must have modified history to a much greater extent than we conceive. Our historians and economists do not seem even to have considered the matter. It is true that they speak of epidemic diseases, but the endemic diseases are really those of the greatest importance. * * *

"The whole life of Greece must suffer from this weight, which crushes its rural energies. Where the children suffer so much, how can the country create that fresh blood which keeps a nation young? But for a hamlet here and there, those famous valleys are deserted. I saw from a spur of Helikon the sun setting upon Parnassus, Apollo sinking, as he was wont to do, towards his own fane at Delphi, and pouring a flood of light over the great Kopaik Plain. But it seemed that he was the only inhabitant of it. There was nothing there. 'Who,' said a rich Greek to me, 'would think of going to live in such a place as that?' I doubt much whether it is the Turk who has done all this. I think it is very largely the malaria."

In considering carefully this suggestive argument of Major Ross does it not appear to indicate the tremendous influence that the prevalence of endemic disease must exert upon the progress of modern nations, and does it not bring the thought that those nations that are most advanced in sanitary science and preventive medicine will, other things being equal, assume the lead in the world's work? Who can estimate the influence of the sanitary laws of the Hebrew scriptures upon the extraordinary persistence of that race through centuries of European oppression—centuries full of plague years and of terrible mortality from preventable disease? And what more striking example can be advanced of the effect of an enlightened and scientifically careful attention to the most recent advances of preventive medicine upon the progress of nations than the mortality statistics of the Japanese armies in the recent Russo-Japanese war as compared with the corresponding statistics for the British army during the Boer war immediately preceding, or for the American Army during the Spanish war at a somewhat earlier date?

The consideration of these elements of national progress has been neglected by historians, but they are nevertheless of deep-reaching importance and must attract immediate attention in this age of advanced civilization. The world has entered the historical age when national greatness and national decay will be based on physical rather than moral conditions, and it is vitally incumbent upon nations to use every possible effort and every possible means to check physical deterioration.

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U. S. DEPARTMENT OF AGRICULTURE,

BUREAU OF ENTOMOLOGY—BULLETIN No. 78 (Revised).

L. O. HOWARD, Entomologist and Chief of Bureau

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R. S. WOGLUM, *in charge of hydrocyanic-acid gas investigations.*
R. P. CURRIE, *in charge of editorial work.*
MABEL COLCORD, *librarian.*

LETTER OF TRANSMITTAL.

U. S. DEPARTMENT OF AGRICULTURE,
BUREAU OF ENTOMOLOGY,
Washington, D. C., April 20, 1909.

SIR: I have the honor to recommend for publication as Bulletin 78, revised, of this Bureau the accompanying slightly revised copy of the original edition of this bulletin, entitled "Economic Loss to the People of the United States Through Insects that Carry Disease," the supply of which is now almost exhausted.

The United States is just awakening to a knowledge of the disastrous results following a lack of appreciation of the danger arising from the unchecked development of mosquitoes and the typhoid fly, and it is hoped that this bulletin will not only emphasize this danger, but will also lend support to movements, both local and widespread, toward the destruction (often so easy) of these carriers of disease.

Respectfully,

L. O. HOWARD,
Entomologist and Chief of Bureau.

HON. JAMES WILSON,
Secretary of Agriculture.

CONTENTS.

ECONOMIC LOSS TO THE PEOPLE OF THE UNITED STATES THROUGH INSECTS THAT CARRY DISEASE.

INTRODUCTION.

It has been definitely proven and is now generally accepted that malaria in its different forms is disseminated among the individuals of the human species by the mosquitoes of the genus Anopheles, and that the malarial organism gains entrance to the human system, so far as known, only by the bite of mosquitoes of this genus. It has been proven with equal definiteness and has also become generally accepted that yellow fever is disseminated by the bite of a mosquito known as *Stegomyia calopus* (possibly by the bites of other mosquitoes of the same genus), and, so far as has been discovered, this disease is disseminated only in this way. Further, it has been scientifically demonstrated that the common house fly is an active agent in the dissemination of typhoid fever, Asiatic cholera, and other intestinal diseases by carrying the causative organisms of these diseases from the excreta of patients to the food supply of healthy individuals; and that certain species of fleas are the active agents in the conveyance of bubonic plague. Moreover, the tropical disease known as filariasis is transmitted by a species of mosquito. Furthermore, it is known that the so-called "spotted fever" of the northern Rocky Mountain region is carried by a species of tick; and it has been demonstrated that certain blood diseases may be carried by several species of biting insects. The purulent ophthalmia of the Nile basin is carried by the house fly. A similar disease on the Fiji Islands is conveyed by the same insect. Pink eye in the southern United States is carried by minute flies of the genus Hippelates. The house fly has been shown to be a minor factor in the spread of tuberculosis. The bedbug has been connected with the dissemination of several diseases. Certain biting flies carry the sleeping sickness in Africa. A number of dangerous diseases of domestic animals are conveyed by insects. The literature of the whole subject has grown enormously during the past few years, and the economic loss to the human species through these insects is tremendous. At the same time, this loss is entirely unnecessary; the diseases in question can be controlled, and the suppression of the conveying insects, so absolutely vital with certain of these diseases and so important in the others, can be brought about.

MOSQUITOES.

Entirely aside from the loss occasioned by mosquitoes as carriers of specific diseases, their abundance brings about a great monetary loss in other ways.

Possibly the greatest of these losses is in the reduced value of real estate in mosquito-infested regions, since these insects render absolutely uninhabitable large areas of land available for suburban homes, for summer resorts, for manufacturing purposes, and for agricultural pursuits. The money loss becomes most apparent in the vicinity of large centers of population. The mosquito-breeding areas in the vicinity of New York City, for example, have prevented the growth of paying industries of various kinds and have hindered the proper development of large regions to an amount which it is difficult to estimate in dollars and cents and which is almost inconceivable. The same may be said for other large cities near the seacoast, and even of those inland in low-lying regions. The development of the whole State of New Jersey has been held back by the mosquito plague.

Agricultural regions have suffered from this cause. In portions of the Northwestern States it has been necessary to cover the work horses in the field with sheets during the day. In the Gulf region of Texas at times the market value of live stock is greatly reduced by the abundance of these insects. In portions of southern New Jersey there are lands eminently adapted to the dairying industry, and the markets of New York, Philadelphia, and the large New Jersey cities are at hand. In these localities herds of cattle have been repeatedly established, but the attacks by swarms of mosquitoes have reduced the yield of milk to such an extent as to make the animals unprofitable, and dairying has been abandoned for less remunerative occupations. The condition of the thoroughbred race horses at the great racing center, Sheepshead Bay, Long Island, was so impaired by the attacks of mosquitoes as to induce those interested to spend many thousands of dollars a few years ago in an effort to abate the pest.

All over the United States, for these insects, and for the house fly as well, it has become necessary at great expense to screen habitations. The cost of screening alone must surely exceed ten millions of dollars per annum.

MALARIA.

The west coast of Africa, portions of India, and many other tropical regions have always, at least down to the present period, been practically uninhabitable by civilized man, owing to the presence of pernicious malaria. The industrial and agricultural development of Italy has been hindered to an incalculable degree by the prevalence of malaria in the southern half of the Italian peninsula, as well as in the valley of the Po and elsewhere. The introduction and spread of malaria in Greece is stated by Ronald Ross, and with strong reasons, to have been largely responsible for the progressive physical degeneration of one of the strongest races of the earth.

In the United States, malaria, if not endemic, was early introduced. The probabilities are that it was endemic, and it is supposed that the cause of the failure of the early colonies in Virginia was due to this disease. It is certain that malaria retarded in a marked degree the advance of civilization over the North American Continent, and particularly was this the case in the march of the pioneers throughout the Middle West and throughout the Gulf States west to the Mississippi and beyond. In many large regions once malarious the disease has lessened greatly in frequency and virulence owing to the reclamation of swamp areas and the lessening of the number of the possible breeding places of the malarial mosquitoes, but the disease is still enormously prevalent, particularly so in the southern United States. There are many communities and many regions in the North where malaria is unknown, but in many of these localities and throughout many of these regions Anopheles mosquitoes breed, and the absence of malaria means simply that malarial patients have not entered these regions at the proper time of the year to produce a spread of the malady. It has happened again and again that in communities where malaria was previously unknown it has suddenly made its appearance and spread in a startling manner. These cases are to be explained, as happened in Brookline, Mass., by the introduction of Italian laborers, some of whom were malarious, to work upon the reservoir; or, as happened at a fashionable summer resort near New York City, by the appearance of a coachman who had had malaria elsewhere and had relapsed at this place. In such ways, with a rapidly increasing population, malaria is still spreading in this country.

To attempt an estimate of the economic loss from the prevalence of malaria in the United States is to attempt a most difficult task. Prof. Irving Fisher, in one of his papers before the recent International Tuberculosis Congress, declared that tuberculosis costs the people of the United States more than a billion dollars each year. In this estimate Professor Fisher considered the death rate for consumption, the loss of the earning capacity of the patients, the period of invalidism, and the amount of money expended in the care of the sick, together with other factors. In making these estimates he had a much more definite basis than can be gained for malaria. The death rate from malaria (as malaria) is comparatively small and is apparently decreasing. Exact figures for the whole country are not available. From a table comprising 22 cities it appears that two-thirds of the deaths from malaria in the United States occur in the South—one-third only in the North. The death rate from malaria by States is available only for the following registration States: California, Colorado, Connecticut, District of Columbia, Indiana, Maine, Maryland, Massachusetts, Michigan, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, South Dakota, and Vermont, all of which are Northern States. For these States the census reports from 1900 to 1907, inclusive, give the following death rates:

TABLE I.—*Deaths due to malaria in the registration States, 1900–1907.*

Year.	Number of deaths from malaria per 100,000 population.	Total deaths from malaria.	Year.	Number of deaths from malaria per 100,000 population.	Total deaths from malaria.
1900	7.9	2,434	1905	3.9	1,321
1901	6.3	1,791	1906	3.5	1,415
1902	5.4	1,738	1907	2.8	1,166
1903	4.3	1,410			
1904	4.2	1,391			12,666

Estimating, from the preceding table, the average annual death rate due to malaria at 4.8 per 100,000 population, and considering that the registration area includes only 16 of the Northern States (assuming fairly, however, that the death rate in the other Northern States is the same), it seems reasonably safe to conclude that the death rate from malaria for the whole United States must surely amount to 15 per 100,000. It is probably greater than this, since the statistics from the South are city statistics, and malaria is really a country disease. Thus it is undoubtedly safe to assume that the death rate for the whole population of the United States is in the neighborhood of 15 per 100,000. This would give an annual death rate from malaria of nearly 12,000 and a total number of deaths for the 8-year period 1900–1907 of approximately 96,000.

But with malaria perhaps as with no other disease does the death rate fail to indicate the real loss from the economic point of view. A man may suffer from malaria throughout the greater part of his life, and his productive capacity may be reduced from 50 to 75 per cent, and yet ultimately he may die from some entirely different immediate cause. In fact, the predisposition to death from other causes brought about by malaria is so marked that if, in the collection of vital statistics, it were possible to ascribe the real influence upon mortality that malaria possesses, this disease would have a very high rank in mortality tables. Writing of tropical countries, Sir Patrick Manson declares that malaria causes more deaths, and more predisposition to death by inducing cachectic states predisposing to other affections, than all the other parasites affecting mankind together. Moreover, it has been shown that the average life of the worker in malarious places is shorter and the infant mortality higher than in healthy places.

But, aside from this vitally important aspect of the subject, the effect of malaria in lessening or destroying the productive capacity of the individual is obviously of the utmost importance, and upon the population of a malarious region is enormous, even under modern conditions and in the United States. It has been suggested that the depopulation of the once thickly settled Roman Campagna was due to the sudden introduction of malaria by the mercenaries of Scylla and Marius. Celli, in 1900, states that owing to malaria about 5,000,000 acres of land in Italy remain—not uncultivated, but certainly very imperfectly cultivated. Then also, in further example, in quite recent years malaria entered and devastated the islands of Mauritius and Réunion, practically destroying for a time the productiveness of these rich colonies of Great Britain and France.

Creighton, in his article on malaria in the Encyclopædia Britannica, states that this disease "has been estimated to produce one-half of the entire mortality of the human race; and inasmuch as it is the most frequent cause of sickness and death in those parts of the globe that are most densely populated, the estimate may be taken as at least rhetorically correct."[a]

Is it possible to make any close estimate of the ratio between the number of deaths from malaria and the number of cases of the same malady? No perfectly sound basis for such an estimate is apparent. In the English translation of Celli's work on "Malaria According to the New Researches," published in London in 1900, it is stated that the mortality from malaria in Italy from 1887 to 1898 varied from 21,033 in the first-named year to 11,378 in the last-named year, and the mean mortality for the period is assumed to be about 15,000. In 1896 a count of the patients in the hospitals in Rome was made, and the mortality rate of 7.75 per thousand of the actual patients was established. Calculating then on this basis, and at this rate, the number of cases per year for Italy was placed at about 2,000,000. According to this estimate, and with the average mortality for the United States of 12,000 as above indicated, the approximate number of cases for the United States would be about 1,550,000. It seems obvious, however, that Celli, in using the basis of hospital patients only, must have underestimated the number of cases for the Kingdom, since of the people in the country suffering from malaria the proportion entering the hospital must be relatively small. Therefore the death rate from malaria of malarial patients in the hospital must be greater than the death rate from malaria of the people who suffer from this disease in the whole country. In fact, so great must this

[a] See "Darwinism and Malaria," by R. G. Eccles, M. D., Medical Record, New York, January 16, 1909, pp. 85–93.

discrepancy necessarily be that it would not seem at all unlikely to the writer if the number of persons suffering from malaria in Italy were in reality nearer 3,000,000 than 2,000,000.

The same argument will hold for the United States, and more especially so since as a rule malaria in this country is of a lighter type than in Italy; in fact an estimate of 3,000,000 cases of malaria in the United States annually is probably by no means too high. It will not be an exaggeration to estimate that one-fourth of the productive capacity of an individual suffering with an average case of malaria is lost. Accepting this as a basis, and including the loss through death, the cost of medicines, the losses to enterprises in malarious regions through the difficulty of securing competent labor, and other factors, it is safe to place the annual loss to the United States from malarial disease under present conditions at not less than one hundred millions of dollars. Celli has shown that in Italy the great railway industries, for example, feel the effect of malaria greatly. According to accurate calculations one company alone, for 1,400 kilometers of railway and for 6,416 workmen in malarious zones, spends on account of malaria 1,050,000 francs a year. The same writer states that the army in Italy from 1877 to 1897 had more than 300,000 cases of malaria.

The loss to this country in the way of retardation of the development of certain regions, owing to the presence of malaria, is extremely great. Certain territory containing most fertile soil and capable of the highest agricultural productiveness is practically abandoned. With the introduction of proper drainage measures and antimosquito work of other character, millions of acres of untold capacity could be released from the scourge at a comparatively slight expenditure. These regions in the absence of malaria would have added millions upon millions to the wealth of the country. Drainage measures are now being initiated by the United States. Parties of engineers are being sent by the Government to make preliminary drainage surveys in the most prominent of these potentially productive regions. The following statement concerning the effect of malaria on the progress of this work has been made to the writer by Dr. George Otis Smith, director of the United States Geological Survey:

"In one of the Southern States 11 topographic parties have been at work during the past field season. The full quota for these parties would be 55 men, but I believe that something over 100 men have been employed at different times during the season. While I have not exact figures before me, I feel warranted in the statement that at least 95 per cent of these employees have been sick, for periods ranging from a few days up to two weeks, in the hospital. Many of them have been able later to return to work, but at least 30 per cent had to leave the field permanently. By reason of this sickness the efficiency of the parties was reduced, at a very conservative estimate, by 25 per cent.

"In my recent visit in this field I found one man sick in each of the parties I saw and one man who had just returned from the hospital leaving the field for good. A similar state of things was reported from the other parties. I regard the sickness as practically all of a malarial nature, as extreme care was taken in all the camps to use nothing but boiled water except in a few instances where artesian water from great depths was available. In all the camps the tents have been screened, and in every case where the topographer has lived for any time 'on the country' there has been infection. As illustrating the value of the precautions generally taken by our camp parties, I might cite the fact that last year in West Virginia with 30 men living in camp, with typhoid fever prevalent in the neighborhood, no cases developed, while with 6 men living on the country where the same care could not be taken regarding the water supply, two cases of typhoid developed."

In estimating the weight of Doctor Smith's statement, it must be borne in mind that the men of his field parties are exceptionally intelligent and prepared to take all ordinary precautions.

Throughout the region in question malaria is practically universal. The railroads suffer, and at the stations throughout the territory it is practically impossible to keep operators steadily at work. This reduction in efficiency in the surveying parties and in the local railroad officials is moreover probably very considerably less than the reduction in the earning capacity of the entire population, which, however, is necessarily scanty.

In an excellent paper entitled "The relation of malaria to agricultural and other industries of the South," published in the Popular Science Monthly for April, 1903, Prof. Glenn W. Herrick, then of the College of Agriculture of Mississippi, after a consideration of the whole field, concludes that malaria is responsible for more sickness among the white population of the South than any disease to which it is now subject. The following forcible statement referring to the States of Louisiana, Mississippi, Alabama, Georgia, and South Carolina is in Professor Herrick's words:

"We must now consider briefly what 635,000 or a million cases of chills and fevers in one year mean. It is a self-evident truth that it means well for the physician. But for laboring men it means an immense loss of their time together with the doctors' fees in many instances. If members of their families other than themselves be affected, it may also mean a loss of time together with the doctors' fees. For the employer it means the loss of labor at a time perhaps when it would be of greatest value. If it does not mean the actual loss of labor to the employer it will mean a loss in the efficiency of his labor. To the farmers it may mean the loss of their crops by want of cultivation. It will always mean the noncultivation or imperfect cultivation of thousands of acres of valuable land. It means a listless activity in the world's work that counts mightily against the wealth-producing power of the people. Finally it means from two to five million or more days of sickness with all its attendant distress, pain of body, and mental depression to some unfortunate individuals of those five States."

Referring to the Delta region in Mississippi, which lies along the Mississippi River in the western part of the State of Mississippi, extending from the mouth of the Yazoo River north nearly to the Tennessee line, Herrick says that it is the second best farming land in the world, having only one rival, and that is the valley of the Nile. "Still," says Herrick, "this land to-day, or at least much of it, can be bought at ten to twenty dollars an acre. Thousands of acres in this region are still covered with the primeval forest, and the bears and deer still roaming there offer splendid opportunities for the chase, as evidenced by the late visit of our Chief Executive to those regions for the purpose of hunting. Why is not this land thickly settled? And why is it not worth from two to five hundred dollars an acre? If it produces from one to two or more bales of cotton to an acre, and it does, it ought to be worth the above named figures. A bale of cotton to the acre can be produced for thirteen dollars, leaving a net profit of twenty to forty dollars for each bale, or forty to eighty or more dollars for each acre of land cultivated. Moreover, this land has been doing that for years, and will do it for years to come, without the addition of one dollar's worth of fertilizer. Land that will produce a net profit of forty to eighty dollars an acre is a splendid investment at one, two, or even three hundred dollars an acre. Yet this land does not sell in the market for anything like so much, because the demand is not sufficient, for white people positively object to living in the Delta on account of malarial chills and fevers. A man said to me not long ago that he would go to the Delta that day if he were sure that his own life or the lives of the members of his family would not be shortened thereby. There are thousands exactly like him, and the only reason that these thousands do not go there to buy lands and make homes is on account of chills and fevers. But there is a time coming, and that not far distant, when malaria in the Delta will not menace the would-be inhabitants. When that time comes it will be the richest and most populous region in the United States."

Malaria is a preventable disease. It is possible for the human species to live and to thrive and to produce in malarious regions, but at a very considerable inconvenience and expense. The Italian investigators, and especially Celli and his staff, have shown that by screening the huts of the peasants on the Roman Campagna and by furnishing field laborers with veils and gloves when exposed to the night air, it is possible even in that famous hotbed of malaria to conduct farming operations with a minimum of trouble from the disease. Moreover, Koch and his assistants in German East Africa have shown that it is possible, by stamping out the disease among human beings by the free use of medicine, that a point can be gained where there is small opportunity for the malarial mosquitoes to become infected. Moreover, the work of the parties sent out by the Liverpool School of Tropical Medicine and other English organizations to the west coast of Africa has shown that by the treatment of malarial-mosquito breeding pools the pernicious coast fever may be greatly reduced. Again, the work of Englishmen in the Federated Malay States has shown that large areas may be practically freed from malaria. The most thorough and the most satisfactory of all measures consists in abolishing the breeding places of the malarial mosquitoes. In regions like the Delta of the Mississippi this involves extensive and systematic drainage, but in very many localities where the breeding places of the Anopheles mosquitoes can be easily eradicated, where they are readily located and are so circumscribed as to admit of easy treatment, it is possible to rid the section of malaria at a comparatively slight expense.

With a general popular appreciation of the industrial losses caused primarily by the malarial mosquito and secondarily by the forms which do not carry malaria, as indicated in the opening paragraphs, it is inconceivable that the comparatively inexpensive measures necessary should not be undertaken by the General Government, by the State governments, and by the boards of health of communities, just as it is inconceivable that the individual should suffer from malaria and from the attacks of other mosquitoes when he has individual preventives and remedies at hand. Large-scale drainage measures by the General Government involving large sections of valuable territory have been planned and are practically under way; certain States, notably New Jersey and New York, are beginning to work; communities all over the country through boards of health are also beginning to take notice, while popular education regarding the danger from mosquitoes and in regard to remedial measures is rapidly spreading. But all of this interest should be intensified, and the importance of the work should be displayed in the most emphatic manner, and relief from malaria and other mosquito conditions should be brought about as speedily as possible.

A few excellent examples of antimalarial work may be instanced.

The latest reports on the measures taken to abolish malaria from Klang and Port Swettenham in Selangor, Federated Malay States, indicate the most admirable results. These measures were undertaken first in 1901 and 1902, and have been reported upon from time to time in the Journal of Tropical Medicine. The expenditure undertaken by the Government with a view to improving the health of the inhabitants of these towns has been fully justified by the results, which promise to be of permanent value. The total expenditure for the town of Klang down to the end of 1905 was £3,100 ($15,086), and the annual permanent expenditure is about £60 ($292) for clearing earth drains and £210 ($1,022) for town gardeners. For Port Swettenham the total expenditure to the end of 1905 was £7,000 ($34,065), and the annual cost of keeping up the drains, etc., is approximately £40 ($195) for clearing earth drains, and £100 ($487) for town gardeners.

The careful tabulation of cases and deaths and of the results of the examination of blood of children in especially drained areas indicates the following conclusions: (1) Measures taken systematically to destroy breeding places of mosquitoes in these towns, the inhabitants of which suffered terribly from malaria, were followed almost immediately by a general improvement in health and decrease in death rate. (2) That this was due directly to the work carried out and not to a general dying out of malaria in the district is clearly shown by figures pointing out that while malaria has practically ceased to exist in the areas treated it has actually increased to a considerable extent in other parts of the district where antimalarial measures have not been undertaken.

The statistics for 1905 are even more favorable than those for 1902, which gives a very strong evidence in favor of the permanent nature of the improvement carried out. In fact it seems as though malaria has been permanently stamped out at Klang and Port Swettenham by work undertaken in 1901, and this experience in the Malay States should be of value to those responsible for the health of communities similarly situated in many other parts of the world.

Another striking example of excellent work of this kind is found in the recently published report on the suppression of malaria in Ismailia, issued under the auspices of the Compagnie Universelle du Canal Maritime de Suez. Ismailia is now a town of 8,000 inhabitants. It was founded by De Lesseps in April, 1862, on the borders of Lake Timsah, which the Suez Canal crosses at mid-distance between the Red Sea and the Mediterranean. Malarial fever made its appearance in very severe form in September, 1877, although the city had up to that time been very healthy, and increased so that since 1886 almost all of the inhabitants have suffered from the fever. In 1901 an attempt to control the disease was made on the mosquito basis, and this attempt rapidly and completely succeeded, and after two years of work all traces of malaria disappeared from the city. The work was directed not only against Anopheles mosquitoes, but against other culicids, and comprised the drainage of a large swamp and the other usual measures. The initial expense amounted to 50,000 francs ($9,650), and the annual expenses since have amounted to about 18,300 francs ($3,532).

The results may be summarized about as follows: Since the beginning of 1903 the ordinary mosquitoes have disappeared from Ismailia. Since the autumn of 1903 not a single larva of Anopheles has been found in the protected zone, which extends to the west for a distance of 1,000 meters from the first houses in the Arabian quarter and to the east for a distance of 1,800 meters from the first houses in the European quarter. After 1902 malarial fever obviously began to decrease, and since 1903 not a single new case of malaria has been found in Ismailia.

A very efficient piece of antimalarial work was accomplished in Havana during the American occupation of 1901 to 1902, incidental in a way to the work against yellow fever. An Anopheles brigade of workmen was organized under the sanitary officer, Doctor Gorgas, for work along the small streams, irrigated gardens, and similar places in the suburbs, and numbered from 50 to 300 men. No extensive drainage, such as would require engineering skill, was attempted, and the natural streams and gutters were simply cleared of obstructions and grass, while superficial ditches were made through the irrigated meadows. Among the suburban truck gardens Anopheles bred everywhere, in the little puddles of water, cow tracks, horse tracks, and similar depressions in grassy ground. Little or no oil was used by the Anopheles brigade, since it was found in practice a simple matter to drain these places. At the end of the year it was very difficult to find water containing mosquito larvæ anywhere in the suburbs, and the effect upon malarial statistics was striking. In 1900, the year before the beginning of the mosquito work, there were 325 deaths from malaria; in 1901, the first year of the mosquito work, 171 deaths; in 1902, the second year of mosquito work, 77 deaths. Since 1902 there has been a gradual though slower decrease, as follows: 1903, 51; 1904, 44; 1905, 32; 1906, 26; 1907, 23. These results, although less striking than those from Ismailia, involved a smaller expense in money and show surely an annual saving of 300 lives, and undoubtedly a corresponding decrease in the number of malarial cases, which may be estimated upon our earlier basis at something less than 40,000.

YELLOW FEVER.

Yellow fever has prevailed endemically throughout the West Indies and in certain regions on the Spanish Main virtually since the discovery of America. Barbados, Jamaica, and Cuba suffered epidemics before the middle of the seventeenth century. There were outbreaks in Philadelphia, Charleston, and Boston as early as 1692, and for a hundred years there were occasional outbreaks, culminating in the great Philadelphia epidemic of 1793. Northern cities were able, by rigid quarantine measures, to prevent great epidemics after the early part of the nineteenth century, but from the West Indies the disease was occasionally introduced and prevailed from time to time epidemically in the Southern States. In 1853 it raged throughout this region, New Orleans alone having a mortality of 8,000. The last widespread epidemic occurred in 1878, chiefly in Louisiana, Alabama, and Mississippi, but spreading up the Mississippi Valley as far as Cairo, Ill., and attacking with virulence the city of Memphis, Tenn. In this year there were 125,000 cases and 12,000 deaths. In 1882 there were 192 deaths at Pensacola; in 1887, 62 deaths in the Southern States; in 1893, 52 deaths; in 1897, 484; in 1898, 2,456 cases with 117 deaths; in 1903, 139 deaths were recorded, mostly at Laredo, Tex., and in 1905 there was a serious outbreak at New Orleans and in neighboring towns, including one locality in Mississippi, in which 911 deaths were recorded for the whole country.

The actual loss of life from yellow fever during all these years, when compared with the loss from other diseases, has been comparatively slight, but the death rate is perhaps the most insignificant feature of the devastation which yellow fever epidemics have produced, and the disease itself has been but a small part of the affliction which it has brought to the Southern States. The disease once discovered in epidemic form, the whole country has become alarmed; commerce in the affected region has come virtually to a standstill; cities have been practically deserted; people have died from exposure in camping out in the highlands; rigid quarantines have been established; innocent persons have been shot while trying to pass these quarantine lines; all industry for the time has ceased. The commerce of the South during the epidemic of 1878, for example, fell off 90 per cent, and the hardships of the population can not be estimated in monetary terms. With such industrial and commercial conditions existing from Texas to South Carolina, many industries at the North have suffered, and, in fact, the effect of a yellow fever summer in the South has been felt not only all over the United States, but in many other portions of the world.

All these conditions, as bad as they have been, do not sum up the total loss to the national prosperity during past years. Cities like Galveston, New Orleans, Mobile, Memphis, Jacksonville, and Charleston, subject to occasional epidemics, as they have been in the past, have not prospered as they should have done. Their progress has been greatly impeded by this one cause, and thus the industrial development of the entire South has been greatly retarded.

Physicians have been theorizing about the cause of yellow fever from the time when they began to treat it. It was thought by many that it was carried in the air; by others that it was conveyed by the clothing, bedding, or other articles which had come in contact with a yellow-fever patient. There were one or two early suggestions of the agency of mosquitoes, but practically no attention was paid to them, and they have been resurrected and considered significant only since the beginning of the present century. With the discovery of the agency of micro-organisms in the causation of disease, a search soon began for some causative germ. Many micro-organisms were found in the course of the autopsies, and many claims were put forth by investigators. All of these, however, were virtually set at rest by Sternberg in his "Report on the Etiology and Prevention of Yellow Fever," published in 1890, but a claim made by Sanarelli in June, 1897, for a bacillus which he called *Bacillus icteroides* received considerable credence, and in 1899 it was accepted in full by Wasden and Geddings, of the United States Marine-Hospital Service, who reported that they had found this bacillus in thirteen or fourteen cases of yellow fever in the city of Havana. There is no evidence, however, that this bacillus has anything to do with yellow fever. In 1881 Finlay, of Havana, proposed the theory that yellow fever, whatever its cause may be, is conveyed by means of *Culex* (now *Stegomyia*) *fasciatus* (now *calopus*). Subsequently he published several important papers, in which his views were modified from time to time, and in the course of which he mentioned experiments with 100 individuals, producing 3 cases of mild fever. None of the cases, however, was under his full control, and the possibility of other methods of contracting the disease was not excluded. Therefore, his theory, while it was received with interest, was not considered to be proved.

In 1900 came the beginning of the true demonstration. An army board was appointed by Surgeon-General Sternberg for the purpose of investigating the acute infectious diseases prevailing in the island of Cuba. The result achieved by this board, consisting of Reed, Carroll, Lazear, and Agramonte, was a demonstration that yellow fever is carried by *Stegomyia calopus*, and their ultimate demonstration was so perfect as to silence practically all expert opposition. The Third International Sanitary Convention of the American Republics unanimously accepted the conclusion that yellow fever is carried by this mosquito, and that the Stegomyia constitutes the only known means by which the disease is spread. To-day, after abundant additional demonstration, the original contention of Reed, Carroll, and Agramonte (Lazear having died in the course of the experiments) is a part of the accepted knowledge of the medical world. The importance of the discovery can not be overestimated, and its first demonstration was followed by antimosquito measures in the city of Havana, undertaken under the direction of Gorgas, with startling results.

Yellow fever had been endemic in Havana for more than one hundred and fifty years, and Havana was the principal source of infection for the rest of Cuba. Other towns in Cuba could have rid themselves of the disease if they had not been constantly reinfected from Havana. By ordinary sanitary measures of cleanliness, improved drainage, and similar means the death rate of the city was reduced, from 1898 to 1900, from 100 per thousand to 22 per thousand; but these measures had no effect upon yellow fever, this disease increasing as the nonimmune population following the Spanish war increased, and in 1900 there was a severe epidemic.

Stegomyia calopus was established as the carrier of the fever early in 1901, and then antimosquito measures were immediately begun. Against adult mosquitoes no general measures were attempted, although screening and fumigation were carried out in quarters occupied by yellow-fever patients or that had been occupied by yellow-fever patients. It was found that the Stegomyia bred principally in the rain-water collections in the city itself. The city was divided into about 30 districts, and to each district an inspector and two laborers were assigned, each district containing about a thousand houses. An order was issued by the mayor of Havana requiring all collections of water to be so covered that mosquitoes could not have access, a fine being imposed in cases where the order was not obeyed. The health department covered the rain-water barrels of poor families at public expense. All cesspools were treated with petroleum. All receptacles containing fresh water which did not comply with the law were emptied and on the second offense destroyed. The result of this work thoroughly done was to wipe out yellow fever in Havana, and there has not been a certain endemic case since that time.

In the New Orleans epidemic of 1905, a striking illustration of the value of this recently acquired mosquito-transmission knowledge is seen. The presence of yellow fever in the city was first recognized about the 12th of July, and the plan of campaign adopted by the Board of Health under Dr. Quitman Kohnke, from the beginning was based on the mosquito conveyance of the disease. Available funds were rapidly exhausted, however, and on the 12th of August the Public Health and Marine-Hospital Service was put in charge of the situation and provided with ample means. By that time the increase in the new cases and deaths rendered it practically certain that the disease was as widespread as during the terrible epidemic of 1878. There had been up to that time 142 deaths from a total of 913 cases, as against 152 deaths from a total of 519 cases in 1878. The work for the rest of the summer was continued with great energy under Doctor White, and the measures were based almost entirely upon a warfare against the yellow-fever mosquito. The disease began almost immediately to abate, and the result at the close of the season indicated 460 deaths, as against 4,046 in 1878, a virtual saving of over 3,500 lives. The following table of deaths from yellow fever in New Orleans from 1847 to 1905 points out most strikingly the value of this antimosquito work:

TABLE II.—*Comparative table of deaths from yellow fever in New Orleans during various years.*

Month.	Year.								
	1847.	1848.	1853.	1854.	1855.	1858.	1867.	1878.	1905.
May	....	....	2	....	....	....	....	....	....
June	....	4	31	2	5	2	3	....	....
July	74	33	1,521	29	382	132	11	26	35
August	965	200	5,133	532	1,286	1,140	255	1,025	236
September	1,100	467	982	1,234	874	2,204	1,637	1,780	107
October	198	126	147	490	97	1,137	1,072	1,065	59
November	12	20	28	131	19	224	103	147	23
December	10	....	4	7	7	15	26	3	....
Months unknown	445	22	....	....	....	....	....	....	....
Total	2,804	872	7,848	2,425	2,670	4,854	3,107	4,046	460

The epidemics of 1848, 1854, and 1855 are least comparable with that of 1905 because they immediately succeeded severe epidemics to which were due very many immunes.

The population of New Orleans by the United States Census was 130,565 in 1850; 168,675 in 1860; 191,418 in 1870; 216,090 in 1880, and 287,104 in 1900.

WORK ON THE ISTHMUS OF PANAMA.

The United States Government has very properly used the services of Colonel Gorgas, who was in charge of the eminently successful work at Havana, by appointing him chief sanitary officer of the Canal Zone during the digging of the canal. In 1904 active work was begun, and Colonel Gorgas was fortunate in having the services of Mr. Le Prince, who had been chief of his mosquito brigades in Havana, and therefore was perfectly familiar with antimosquito methods. In Panama, as in Havana, the population had depended principally upon rain water for domestic purposes, so that every house had cisterns, water barrels, and such receptacles for catching and storing rain water. The city was divided up into small districts with an inspector in charge of each district. This inspector was required to cover his territory at least twice a week and to make a report upon each building with regard to its condition as to breeding places of mosquitoes. All the cisterns, water barrels, and other water receptacles in Panama were covered as in Havana, and in the water barrels spigots were inserted so that the covers would not have to be taken off. Upon first inspection, in March, 4,000 breeding places were reported. At the end of October less than 400 containing larvæ were recorded. This gives one a fair idea of the consequent rapid decrease in the number of mosquitoes in the city. These operations were directed primarily against the yellow-fever mosquito, and incidentally against the other common species that inhabit rain-water barrels. Against the Anopheles in the suburbs the same kind of work was done as was done in Havana, with exceptionally good results.

The same operations were carried on in the villages between Panama and Colon. There are some twenty of these villages, running from 500 to 3,000 inhabitants each. Not a single instance of failure has occurred in the disinfection of these small towns, and the result of the whole work has been the apparent elimination of yellow fever and the very great reduction of malarial fever.

The remarkable character of these results can only be judged accurately by comparative methods. It is well known that during the French occupation there was an enormous mortality among the European employees, and this was a vital factor in the failure of the work. Exact losses can not be estimated, since the work was done under 17 different contractors. These contractors were charged $1 a day for every sick man to be taken care of in the hospital of the company. Therefore it often happened that when a man became sick his employer discharged him, so that he would not have to bear the expense of hospital charges. There was no police patrol of the territory and many of these men died along the line. Colonel Gorgas has stated that the English consul, who was at the Isthmus during the period of the French occupation, is inclined to think that more deaths of employees occurred out of the hospital than in it. A great many were found to have died along the roadside while endeavoring to find their way to the city of Panama. The old superintendent of the French hospital states that one day 3 of the medical staff died from yellow fever, and in the same month 9 of the medical staff. Thirty-six Roman Catholic sisters were brought over as nurses, and 24 died of yellow fever. On one vessel 18 young French engineers came over, and in a month after their arrival all but one died.

Now that the relation of the mosquito to yellow fever is well understood, it was found during the first two years under Doctor Gorgas that, although there were constantly one or more yellow-fever cases in the hospital, and although the nurses and physicians were all nonimmunes, not a single case of yellow fever was contracted in that way. The nurses never seemed to consider that they were running any risk in attending yellow fever cases night and day in screened wards, and the wives and families of officers connected with the hospital lived about the grounds, knowing that yellow fever was constantly being brought into the grounds and treated in near-by buildings. Americans, sick from any cause, had no fear when being treated in beds immediately adjoining those of yellow-fever patients. Colonel Gorgas and Doctor Carter lived in the old ward used by the French for their officers, and Colonel Gorgas thinks it safe to say that more men had died from yellow fever in that building under the French régime than in any other building of the same capacity at present standing. He and Doctor Carter had their wives and children with them, which would formerly have been considered the height of recklessness, but they looked upon themselves, under the now recognized precautions, as being as safe, almost, as they would have been in Philadelphia or Boston.

No figures of the actual cost of the antimosquito work, either in Havana or in the Panama Canal Zone, are accessible to the writer, but it is safe to say that it was not exorbitant, and that it was not beyond the means of any well-to-do community in tropical regions.

THE TYPHOID FLY, COMMONLY KNOWN AS THE HOUSE FLY.

The name "typhoid fly" is here proposed as a substitute for the name "house fly," now in general use. People have altogether too long considered the house fly as a harmless creature, or, at the most, simply a nuisance. While scientific researches have shown that it is a most dangerous creature from the standpoint of disease, and while popular opinion is rapidly being educated to the same point, the retention of the name house fly is considered inadvisable, as perpetuating in some degree the old ideas. Strictly speaking, the term "typhoid fly" is open to some objection, as conveying the erroneous idea that this fly is solely responsible for the spread of typhoid, but considering that the creature is dangerous from every point of view, and that it is an important element in the spread of typhoid, it seems advisable to give it a name which is almost wholly justified and which conveys in itself the idea of serious disease. Another repulsive name that might be given to it is "manure fly," but recent researches have shown that it is not confined to manure as a breeding place, although perhaps the great majority of these flies are born in horse manure. For the end in view, "typhoid fly" is considered the best name.

The true connection of the so-called house fly with typhoid fever and the true scientific evidence regarding its rôle as a carrier of that disease have only recently been worked out. Celli in 1888 fed flies with pure cultures of the typhoid bacillus, and examined their contents and dejections microscopically and culturally. Inoculations of animals were also made, proving that the bacilli which passed through flies were virulent. Dr. George M. Kober, familiar with Celli's researches, in his report on the prevalence of typhoid fever in the District of Columbia, published in 1895, called especial attention to the danger of the contamination of food supplies by flies coming from the excreta of typhoid patients. The prevalence of typhoid fever in the concentration camps of the United States Army in the summer of 1898 brought about the appointment of an army board of medical officers consisting of Drs. Walter Reed, U. S. Army, Victor C. Vaughan, U. S. Volunteers, and E. O. Shakespeare, U. S. Volunteers, to investigate the causes. The abstract of the report of this board, published in 1900, contains (p. 183) the following conclusions with regard to flies:

"*Flies undoubtedly served as carriers of the infection.*

"Flies swarmed over infected fecal matter in the pits and then visited and fed upon the food prepared for the soldiers at the mess tents. In some instances where lime had recently been sprinkled over the contents of the pits, flies with their feet whitened with lime were seen walking over the food.

"It is possible for the fly to carry the typhoid bacillus in two ways. In the first place, fecal matter containing the typhoid germ may adhere to the fly and be mechanically transported. In the second place, it is possible that the typhoid bacillus may be carried in the digestive organs of the fly and may be deposited with its excrement."

Doctor Vaughan, of the board just mentioned, in a paper read before the annual meeting of the American Medical Association at Atlantic City, N. J., June 6, 1900, gives the following additional reasons for believing that flies were active in the dessemination of typhoid fever:

"Officers whose mess tents were protected by means of screens suffered proportionately less from typhoid fever than did those whose tents were not so protected.

"Typhoid fever gradually disappeared in the fall of 1898, with the approach of cold weather, and the consequent disabling of the fly."

There were also many important conclusions which bear upon the fly question. For example, it was shown that every regiment in the United States service in 1898 developed typhoid fever, nearly all of them within eight weeks after assembling in camps. It not only appeared in every regiment in the service, but it became epidemic both in small encampments of not more than one regiment and in the larger ones consisting of one or more corps. All encampments located in the Northern as well as in the Southern States exhibited typhoid in epidemic form. The miasmatic theory of the origin of typhoid fever and the pythogenic theory[a] were not supported by the investigations of the commission, but the doctrine of the specific

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[a] This theory is founded upon the belief that the colon germ may undergo a ripening process by means of which its virulence is so increased and altered that it may be converted into the typhoid bacillus or at least may become the active agent in the causation of typhoid fever.

origin of the fever was confirmed. The conclusion was reached that the fever is disseminated by the transference of the excretions of an infected individual to the alimentary canals of others, and that a man infected with typhoid fever may scatter the infection in every latrine or regiment before the disease is recognized in himself, while germs may be found in the excrement for a long time after the apparently complete recovery of the patient. Infected water was not an important factor in the spread of typhoid in the national encampments of 1898, but about one-fifth of the soldiers in the national encampments in the United States during that summer developed this disease, while more than 80 per cent of the total deaths were caused by typhoid.

In 1899 the writer began the study of the typhoid or house fly under both country and city conditions. He made a rather thorough investigation of the insect fauna of human excrement, and made a further investigation of the species of insects that are attracted to food supplies in houses. In a paper entitled "A Contribution to the Study of the Insect Fauna of Human Excrement (with special reference to the spread of typhoid fever by flies)," published in the Proceedings of the Washington Academy of Sciences, Volume II, pages 541–604, December 28, 1900, he showed that 98.8 per cent of the whole number of insects captured in houses throughout the whole country under the conditions indicated above were *Musca domestica*, the typhoid or house fly. He showed further that this fly, while breeding most numerously in horse stables, is also attracted to human excrement and will breed in this substance. It was shown that in towns where the box privy was still in existence the house fly is attracted to the excrement, and, further, that it is so attracted in the filthy regions of a city where sanitary supervision is lax and where in low alleys and corners and in vacant lots excrement is deposited by dirty people. He stated that he had seen excrement which had been deposited overnight in an alleyway in South Washington swarming with flies under the bright sunlight of a June morning (temperature 92° F.), and that within 30 feet of these deposits were the open windows and doors of the kitchens of two houses kept by poor people, these two houses being only elements in a long row. The following paragraph is quoted from the paper just cited:

"Now, when we consider the prevalence of typhoid fever and that virulent typhoid bacilli may occur in the excrement of an individual for some time before the disease is recognized in him, and that the same virulent germs may be found in the excrement for a long time after the apparent recovery of a patient, the wonder is not that typhoid is so prevalent but that it does not prevail to a much greater extent. Box privies should be abolished in every community. The depositing of excrement in the open within town or city limits should be considered a punishable misdemeanor in communities which have not already such regulations, and it should be enforced more rigorously in towns in which it is already a rule. Such offenses are generally committed after dark, and it is often difficult or even impossible to trace the offender; therefore, the regulation should be carried even further and require the first responsible person who notices the deposit to immediately inform the police, so that it may be removed or covered up. Dead animals are so reported; but human excrement is much more dangerous. Boards of health in all communities should look after the proper treatment or disposal of horse manure, primarily in order to reduce the number of house flies to a minimum, and all regulations regarding the disposal of garbage and foul matter should be made more stringent and should be more stringently enforced."

In the opening sentence of the paragraph just quoted attention was called to the activity of bacilli in excreta passed by individuals after apparent recovery from typhoid. Since the paper in question was published, more especial attention has been drawn by medical men to this point, and it has been shown that individuals who are chronic spreaders of the typhoid germs are much more abundant than was formerly supposed. Dr. George A. Soper recently discovered a striking case of this kind in the person of a cook employed successively by several families in the vicinity of New York City, with the result that several cases of typhoid occurred in each of these families. In a paper by Doctor Davids and Professor Walker, read before the Royal Sanitary Institute of London during the present season, the history was given of four personal carriers of typhoid who had communicated the disease to a number of people. These four carriers were detected in one city within a few months, and from this fact it can be argued with justice that such cases are comparatively numerous. This being true, the presence of unguarded miscellaneous human excreta deposited in city suburbs, in vacant lots, and in low alleyways intensifies to a very marked degree the danger that the food will become contaminated with typhoid bacilli by means of the typhoid or house fly. It is known, too, that the urine of persons who have suffered from typhoid fever often contains active typhoid bacilli for several weeks after the patients have recovered; consequently this also is a source of danger.

The importance of the typhoid fly as a carrier of the disease in army camps, as shown in the Spanish war and in the Boer war and in the camps of great armies of laborers engaged in gigantic enterprises like the digging of the Panama canal, is obvious, but what has just been stated indicates that even under city conditions the influence of this fly in the spread of this disease has been greatly underestimated. It is not claimed that under city conditions the house fly becomes by this argument a prime factor in the transfer of the disease, but it must obviously take a much higher relative rank among typhoid conveyers than it has hitherto assumed. Perhaps even under city conditions it must assume third rank—next to water and milk.[a]

It is not alone as a carrier of typhoid that this fly is to be feared. In the same way it may carry nearly all the intestinal diseases. It is a prime agent in the spreading of summer dysentery, and in this way is unquestionably responsible for the death of many children in summer. One of the earliest accurate scientific studies of the agency of insects in the transfer of human disease was in regard to flies as spreaders of cholera. The belief in this agency long preceded its actual proof. Dr. G. E. Nicholas, in the London Lancet, Volume II, 1873, page 724, is quoted by Nuttall as writing as follows regarding the cholera prevailing at Malta in 1849: "My first impression of the possibility of the transfer of the disease by flies was derived from the observation of the manner in which these voracious creatures, present in great numbers, and having equal access to the dejections and food of patients, gorged themselves indiscriminately and then disgorged themselves on the food and drinking utensils. In 1850 the *Superb*, in common with the rest of the Mediterranean squadron, was at sea for nearly six months; during the greater part of the time she had cholera on board. On putting to sea, the flies were in great force; but after a time the flies gradually disappeared, and the epidemic slowly subsided. On going into Malta Harbor, but without communicating with the shore, the flies returned in greater force, and the cholera also with increased violence. After more cruising at sea, the flies disappeared gradually with the subsidence of the disease."

Accurate scientific bacteriological observations by Tizzoni and Cattani in 1886 showed definitely active cholera organisms in the dejecta of flies caught in the cholera wards in Bologna, Italy. These observations were subsequently verified and extended by Simonds, Offelmann, Macrae, and others.

With tropical dysentery and other enteric diseases practically the same conditions exist. In a report by Daniel D. Jackson to the committee on pollution, of the Merchants' Association in New York, published in December, 1907, the results of numerous observations upon the relation of flies to intestinal diseases are published, and the relation of deaths from intestinal diseases in New York City to the

[a] Dr. John R. Mohler, of the Bureau of Animal Industry, U. S. Department of Agriculture, informs the writer that investigations made in his office show that typhoid bacilli will live in butter under common market conditions for 151 days and still be able to grow when transferred to suitable conditions. In milk under market conditions they retain active motility for 20 days, after which time there is a gradual lessening in numbers until, on the forty-third day of the test, they disappear from view. At certain seasons of the year large numbers of flies collect upon the vats in which milk and cream are being stored in dairies and creameries. Many of the flies fall in, their bodies being strained out when the cream is sent to the churn. If any of these flies carry typhoid bacilli these are washed off by the milk and remain in the butter or cheese made from it. Thus the eating of butter contaminated in this way may account for very many cases of typhoid fever the cause of which can not be otherwise traced.

activity and prevalence of the common house fly is shown not only by repeated observations but also by an interesting plotting of the curve of abundance of flies in comparison with the plotted curve of abundance of deaths from intestinal diseases, indicating that the greatest number of flies occurred in the weeks ending July 27 and August 3; also, that the deaths from intestinal diseases rose above the normal at the same time at which flies became prevalent, culminated at the same high point, and fell off with slight lag at the time of the gradual falling off of the prevalence of the insects.

Similar studies have been carried on during the summer of 1908 in the city of Washington, and the curve of typhoid-fly abundance for the whole city, as well as that for a district comprising eight city squares in which intensive studies have been made both of flies and of disease, will be plotted at the close of the season. At the time of present writing this work has not been completed.

The typhoid fly also possesses importance as a disseminator of the bacilli of tuberculosis. In a paper by Dr. Frederick T. Lord, of Boston, reprinted from the Boston Medical and Surgical Journal for December 15, 1904, pages 651-654, the following conclusions are reached:

"1. Flies may ingest tubercular sputum and excrete tubercle bacilli, the virulence of which may last for at least fifteen days.

"2. The danger of human infection from tubercular flyspecks is by the ingestion of the specks on food. Spontaneous liberation of tubercle bacilli from flyspecks is unlikely. If mechanically disturbed, infection of the surrounding air may occur.

"As a corollary to these conclusions, it is suggested that—

"3. Tubercular material (sputum, pus from discharging sinuses, fecal matter from patients with intestinal tuberculosis, etc.) should be carefully protected from flies, lest they act as disseminators of the tubercle bacilli.

"4. During the fly season greater attention should be paid to the screening of rooms and hospital wards containing patients with tuberculosis and laboratories where tubercular material is examined.

"5. As these precautions would not eliminate fly infection by patients at large, foodstuffs should be protected from flies which may already have ingested tubercular material."

From all these facts it appears that the most important part played by the typhoid fly or house fly in the human economy is to carry bacteria from one place to another. The following table and comments are taken from Bulletin No. 51 (April, 1908), of the Storrs Agricultural Experiment Station, Storrs, Conn., entitled "Sources of Bacteria in Milk," by W. M. Esten and C. J. Mason:

TABLE III.—*Sources of bacteria from flies.*

Date.	Source.	Total number.	Total acid bacteria.	Rapid liquefying bacteria.	Slow liquefying bacteria.	*Bacterium lactis acidi.* Group A. Class 1.	*Coli-ærogenes.* Group A. Class 2.
1907. July 27	(*a*) 1 fly, bacteriological laboratory	3,150	250	600	100	....	....
July 27	(*b*) 1 fly, bacteriological laboratory	550	100	0	0		
Aug. 6	(*c*) 19 cow-stable flies	7,980,000	220,000	0	20,000	....	....
	Average per fly	420,000	11,600	0	1,000	....	....
Aug. 14	(*d*) 94 swill-barrel flies	155,000,000	8,950,000	0	0	4,320,000	4,630,000
	Average per fly	1,660,000	95,300	0	0	46,000	49,300
Aug. 14	(*e*) 144 pigpen flies	133,000,000	2,110,000	100,000	266,000	933,000	1,176,000
	Average per fly	923,000	18,700	700	1,150	6,500	12,200
Sept. 4	(*f*) 18 swill-barrel flies	118,800,000	40,480,000	0	14,500,000	10,480,000	30,000,000
	Average per fly	6,600,000	2,182,000	0	804,000	582,000	1,600,000
Sept. 21	(*g*) 30 dwelling-house flies	1,425,000	125,000	0	12,500	....	....
	Average per fly	47,580	4,167	0	417	....	....
Sept. 21	(*h*) 26 dwelling-house flies	22,880,000	22,596,000	120,000	34,000	....	....
	Average per fly	880,000	869,000	4,600	1,300	....	....
Sept. 27	(*i*) 110 dwelling-house flies	35,500,000	13,670,000	8,840,000	125,000	....	....
	Average per fly	322,700	124,200	80,300	1,100	....	....
Aug. 20	(*j*) 1 large bluebottle blowfly	308,700	(*a*)	....	....	....	....
	Total average of 414 flies	1,222,570	367,300	7,830	73,500	....	....
	Average per cent of 414 flies	....	30	6	6	....	....
	Average per fly of 256 flies, experiments (*d*), (*e*), and (*f*)	3,061,000	765,000	230	268,700	211,500	553,800
	Average per cent of 256 flies, experiments (*d*), (*e*), and (*f*)	....	25	....	8	7	18

[a] 2,200 mold spores.

"From the above table the bacterial population of 414 flies is pretty well represented. The domestic fly is passing from a disgusting nuisance and troublesome pest to a reputation of being a dangerous enemy to human health. A species of mosquito has been demonstrated to be the cause of the spread of malaria. Another kind of mosquito is the cause of yellow fever, and now the house fly is considered an agency in the distribution of typhoid fever, summer complaint, cholera infantum, etc.

"The numbers of bacteria on a single fly may range all the way from 550 to 6,600,000. Early in the fly season the numbers of bacteria on flies are comparatively small, while later the numbers are comparatively very large. The place where flies live also determines largely the numbers that they carry. The average for the 414 flies was about one and one-fourth million bacteria on each. It hardly seems possible for so small a bit of life to carry so large a number of organisms. The method of the experiment was to catch the flies from the several sources by means of a sterile fly net, introduce them into a sterile bottle, and pour into the bottle a known quantity of sterilized water, then shake the bottle to wash the bacteria from their bodies, to simulate the number of organisms that would come from a fly in falling into a lot of milk. In experiments '*d*,' '*e*,' and '*f*' the bacteria were analyzed into four groups. The objectionable class, *coli-aerogenes* type, was two and one-half times as abundant as the favorable acid type. If these flies stayed in the pigpen vicinity there would be less objection to the flies and the kinds of organisms they carry, but the fly is a migratory insect and it visits everything 'under the sun.' It is almost impossible to keep it out of our kitchens, dining rooms, cow stables, and milk rooms. The only remedy for this rather serious condition of things is, remove the pigpen as far as possible from the dairy and dwelling house. Extreme care should be taken in keeping flies out of the cow stable, milk rooms, and dwellings. Flies walking over our food are the cause of one of the worst contaminations that could occur from the standpoint of cleanliness and the danger of distributing disease germs."

The danger of the typhoid or house fly in the carriage of disease has thus been abundantly demonstrated. Further than this, it is an intolerable nuisance. With mosquitoes it necessitates an annual outlay for window and door screens in the United States of not less than ten millions of dollars. As a carrier of disease it causes a loss of many millions of dollars annually. Dr. G. N. Kober, in a paper prepared for the Governors' Conference on the Conservation of Natural Resources, held at the White House in May, 1908, entitled "The Conservation of Life and Health by Improved Water Supply," presented figures showing that the decrease in the vital assets of the country through typhoid fever in a single year is more than $350,000,000. The house fly, as an important agent in the spread of this disease, is responsible for a very considerable portion of this decrease in vital assets. As an agency in the spread of other intestinal diseases, this sum must be greatly increased, and yet it is allowed to breed unrestricted all over the United States; it is allowed to enter freely the houses of the great majority of our people; it is allowed to spread bacteria freely over our food supplies in the markets and in the kitchens and dining rooms of private houses, and, to use the happy phraseology of Dr. Theobald Smith, "when we go into public restaurants in midsummer we are compelled to fight for our food with the myriads of house flies which we find there alert, persistent, and invincible."

Even if the typhoid or house fly were a creature difficult to destroy, the general failure on the part of communities to make any efforts whatever to reduce its numbers could properly be termed criminal neglect; but since, as will be shown, it is comparatively an easy matter to do away with the plague of flies, this neglect becomes an evidence of ignorance or of a carelessness in regard to disease-producing filth which to the informed mind constitutes a serious blot on civilized methods of life.

Strange as it may seem, an exhaustive study of the conditions which produce house flies in numbers has never been made. The life history of the insect in general was, down to 1873, mentioned in only three European works and few exact facts were given. In 1873 Dr. A. S. Packard, then of Salem, Mass., studied the transformations of the insect and gave descriptions of all stages, showing that the growth of a generation from the egg state to the adult occupies from 10 to 14 days.

In 1895 the writer traced the life history in question, indicating that 120 eggs are laid by a single female, and that in Washington, in midsummer, a generation is produced every 10 days. Although numerous substances were experimented with, he was able to breed the fly only in horse manure. Later investigations indicated that the fly will breed in human excrement and in other fermenting vegetable and animal material, but that the vast majority of the flies that infest dwelling houses, both in cities and on farms, come from horse manure.

In 1907 careful investigations carried on in the city of Liverpool by Robert Newstead, lecturer in economic entomology and parasitology in the School of Tropical Medicine of the University of Liverpool, indicated that the chief breeding places of the house fly in that city should be classified under the following heads:

(1) Middensteads (places where dung is stored) containing horse manure only.

(2) Middensteads containing spent hops.

(3) Ash pits containing fermenting materials.

He found that the dung heaps of stables containing horse manure only were the chief breeding places. Where horse and cow manures were mixed the flies bred less numerously, and in barnyards where fowls were kept and allowed freedom relatively few of the house flies were found. Only one midden containing warm spent hops was inspected, and this was found to be as badly infested as any of the stable middens. A great deal of time was given to the inspection of ash pits, and it was found that wherever fermentation had taken place and artificial heat had been thus produced, such places were infested with house-fly larvæ and pupæ, often to the same alarming extent as in stable manure. Such ash pits as these almost invariably contained large quantities of old bedding or straw and paper, paper mixed with human excreta, or old rags, manure from rabbit hutches, etc., or a mixture of all these. About 25 per cent of the ash pits examined were thus infested, and house flies were found breeding in smaller numbers in ash pits in which no heat had been engendered by fermentation. The house fly was also found breeding by Mr. Newstead in certain temporary breeding places, such as collections of fermenting vegetable refuse, accumulations of manure at the wharves, and in bedding in poultry pens.

Still more recent investigations were carried on during 1908 by Prof. S. A. Forbes, State entomologist of Illinois, who has reared it in large numbers from the contents of paunches of slaughtered cattle, from refuse hog hairs, from tallow vats, from carcasses of various animals, miscellaneous garbage, and so on.

All this means that if we allow the accumulation of filth we will have house flies, and if we do not allow it to accumulate we will have no house flies. With the careful collection of garbage in cans and the removal of the contents at more frequent intervals than 10 days, and with the proper regulation of abattoirs, and more particularly with the proper regulation of stables in which horses are kept, the typhoid fly will become a rare species. It will not be necessary to treat horse manure with chlorid of lime or with kerosene or with a solution of Paris green or arsenate of lead, if stable men are required to place the manure daily in a properly covered receptacle and if it is carried away once a week.

The orders of the health department of the District of Columbia, published May 3, 1906, if carried out will be very effective. These orders may be briefly condensed as follows:

All stalls in which animals are kept shall have the surface of the ground covered with a water-tight floor. Every person occupying a building where domestic animals are kept shall maintain, in connection therewith, a bin or pit for the reception of manure, and pending the removal from the premises of the manure from the animal or animals shall place such manure in said bin or pit. This bin shall be so constructed as to exclude rain water, and shall in all other respects be water-tight, except as it may be connected with the public sewer. It shall be provided with a suitable cover and constructed so as to prevent the ingress and egress of flies. No person owning a stable shall keep any manure or permit any manure to be kept in or upon any portion of the premises other than the bin or pit described, nor shall he allow any such bin or pit to be overfilled or needlessly uncovered. Horse manure may be kept tightly rammed into well-covered barrels for the purpose of removal in such barrels. Every person keeping manure in any of the more densely populated parts of the District shall cause all such manure to be removed from the premises at least twice every week between June 1 and October 31, and at least once every week between November 1 and May 31 of the following year. No person shall remove or transport any manure over any public highway in any of the more densely populated parts of the District except in a tight vehicle, which, if not inclosed, must be effectually covered with canvas, so as to prevent the manure from being dropped. No person shall deposit manure removed from the bins or pits within any of the more densely populated parts of the District without a permit from the health officer. Any person violating any of these provisions shall, upon conviction thereof, be punished by a fine of not more than $40 for each offense.

In addition to this excellent ordinance, others have been issued from the health department of the District of Columbia which provide against the contamination of exposed food by flies and by dust. The ordinances are excellently worded so as to cover all possible cases. They provide for the registration of all stores, markets, cafés, lunch rooms, or of any other place where food or beverage is manufactured or prepared for sale, stored for sale, offered for sale, or sold, in order to facilitate inspection, and still more recent ordinances provide for the registration of stables. An excellent campaign was begun during the summer of 1908 against insanitary lunch rooms and restaurants. A number of cases were prosecuted, but conviction was found to be difficult.

For one reason or another, the chief reason being the lack of a sufficient force of inspectors under the control of the health officers, the ordinance in regard to stables has not been carried out with that perfection which the situation demands. In the summer of 1896, the health officer of the District, Dr. W. C. Woodward, designated a region in Washington bounded by Pennsylvania avenue, Sixth street, Fifteenth street, and the Potomac River, which was to be watched by assistants of the writer. Twenty-four stables were located in this region and were visited weekly by two assistants chosen for the purpose. The result was that on the whole the manure was well looked after and the number of flies in the region in question was very considerably reduced during the time of inspection.

Were simple inspection of stables all that is needed, a force of four inspectors, specially detailed for this work, could cover the District of Columbia, examining every stable, after they were once located and mapped, once a week. The average salary of an inspector is $1,147, so that the total expense for the first year would be something like $4,500. But the inspectors' service is complicated by the matter of prosecution. Much of the time of inspectors would be taken in the prosecution of the owners of neglected premises. Moreover, the health officer has found during the summer of 1908, in his prosecution of the owners or managers of insanitary restaurants, that his inspectors were practically sworn out of court by the multiplicity of opposing evidence. This means that it will be necessary in such cases to send two inspectors together in all cases, so that the testimony of one may be supported by the testimony of the other. This, perhaps, would double the number of necessary inspectors, making the expense of the service something over $9,000. It is reasonably safe to state, however, that with such an expense for competent service, or perhaps with a slightly added expense, the typhoid fly could be largely eliminated as an element in the transfer of disease in the District of Columbia, and the difficulty which the authorities have had in locating the cause of a very considerable proportion of the cases of typhoid in the District for the past two or three years indicates plainly to the mind of the writer that the typhoid fly is a much more important element than has been supposed. It is a comforting although comparatively insignificant fact and a matter of common observation that in certain sections of the city the typhoid fly has been much less numerous during the past summer than in previous years. The writer is inclined to attribute this to the gradual disappearance of horse stables in such sections, brought about by the rapidly increasing use of motor vehicles.

A significant paragraph in Mr. Newstead's Liverpool report, referred to above, contains the following words: "The most strenuous efforts should be made to prevent children defecating in the courts and passages; or that the parents should be compelled to remove such matter immediately; and that defecation in stable middens should be strictly forbidden. The danger lies in the overwhelming attraction which such fecal matter has for house flies, which later may come into direct contact with man or his foodstuffs. They may, as Veeder puts it, 'In a very few minutes * * * load themselves with dejections from a typhoid or dysenteric patient, not as yet sick enough to be in hospital or under observation, and carry the poison so taken up into the very midst of the food and water ready for use at the next meal. There is no long, roundabout process involved.'"

The writer has already referred to this general subject in his remarks on the depositing of excrement in the open within town or city limits, but Newstead's specific reference to children reminds one that in the tenement districts of the older great cities of England and other parts of Europe there occur opportunities for transfer of disease which, while probably less numerous in the newer cities of the United States, nevertheless must still exist and be a constant danger.

We have thus shown that the typhoid or house fly is a general and common carrier of pathogenic bacteria. It may carry typhoid fever, Asiatic cholera, dysentery, cholera morbus, and other intestinal diseases; it may carry the bacilli of tuberculosis and certain eye diseases; it is everywhere present, and it is disposed of with comparative ease. It is the duty of every individual to guard so far as possible against the occurrence of flies upon his premises. It is the duty of every community, through its board of health, to spend money in the warfare against this enemy of mankind. This duty is as pronounced as though the community were attacked by bands of ravenous wolves.

As a matter of fact, large sums of money are spent annually in the protection of property in the United States. Large sums of money are spent also in health matters; but the expenditure for protection from flies is very small and is misdirected. There is much justification for the following criticism published editorially in the Journal of the American Medical Association for August 22, 1908, under the caption, "National Farm Commission and Rural Sanitation:"

"The President calls attention to the fact that all efforts to aid the farmers have hitherto been directed to improving their material welfare, while the man himself and his family have been neglected. Nowhere is this more marked than in the attitude of the General Government in matters relating to sanitation. It is a trite saying that whereas the Government, through the Department of Agriculture, aids the farmer generously in caring for the health of his hogs, sheep, etc., it does nothing for his own health. The Government issues notices to the farmer of the injury done to his crops by the cotton-boll weevil and the potato bugs and how to combat them, but the injury the mosquito does in spreading malaria to the people who pick the cotton and hoe the potatoes is not impressed on him. The fact that horseflies may carry anthrax to his cattle is dealt with at considerable length, but the diseases which the house fly spreads to the milk and to the farmer's family attract practically no attention. How to build a hogpen or a sanitary barn is the subject of a number of government publications, but how to build a sanitary privy which will prevent the spread of typhoid, hook worm, and many other diseases is regarded as of strictly local interest."

But this criticism is not entirely justified, since there was published by the Bureau of Entomology of the United States Department of Agriculture, in 1900, a Farmers' Bulletin, entitled "How Insects Affect Health in Rural Districts,"[a] in which all of these points mentioned by the editor of the Journal of the American Medical Association have been touched upon, and at the date of present writing 192,000 copies of this bulletin have been distributed among the people. Moreover, a number of years ago a circular[b] was published on the subject of the house fly, calling attention to its dangers and giving instructions such as are covered in a general way in this article, and some 18,000 copies of this circular have also been distributed. This is an indication that the General Government is by no means blind to the people's needs in such matters as we have under consideration, but further work should be done. That the English Government is awaking to the same need is shown by the fact that, in the parliamentary vote of the present year in aid of

[a] Farmers' Bulletin No. 155.

[b] Circular No. 35, Bureau of Entomology, 1891, afterwards reissued in revised form as Circular No. 71.

scientific investigations concerning disease, one of the projects supported by the General Government was the investigation of Doctors Copeman and Nuttall on flies as carriers of disease.

A leading editorial in an afternoon paper of the city of Washington, of October 20, 1908, bears the heading, "Typhoid a National Scourge," arguing that it is to-day as great a scourge as tuberculosis. The editorial writer might equally well have used the heading "Typhoid a National Reproach," or perhaps even "Typhoid a National Crime," since it is an absolutely preventable disease. And as for the typhoid fly, that a creature born in indescribable filth and absolutely swarming with disease germs should practically be invited to multiply unchecked, even in great centers of population, is surely nothing less than criminal.

ENDEMIC DISEASE AS AFFECTING THE PROGRESS OF NATIONS.

In referring to the spread of malaria in Greece, the relation of this disease to the rise and fall of national power has been touched upon in an earlier paragraph of this bulletin (p. 9). The subject is one of the widest importance and deserves a more extended consideration.

The following paragraphs are quoted from Ronald Ross's address on Malaria in Greece, delivered before the Oxford Medical Society, November 29, 1906:

"Now, what must be the effect of this ubiquitous and everlasting incubus of disease on the people of modern Greece? Remember that the malady is essentially one of infancy among the native population. Infecting the child one or two years after birth, it persecutes him until puberty with a long succession of febrile attacks, accompanied by much splenomegaly and anæmia. Imagine the effect it would produce upon our own children here in Britain. It is true that our children suffer from many complaints—scarlatina, measles, whooping cough—but these are of brief duration and transient. But now add to these, in imagination, a malady which lasts for years, and may sometimes attack every child in a village. What would be the effect upon our population—especially our rural population—upon their numbers and upon the health and vigour of the survivors? It must be enormous in Greece. People often seem to think that such a plague strengthens a race by killing off the weaker individuals; but this view rests upon the unproven assumption that it is really the weaker children which can not survive. On the contrary, experience seems to show that it is the stronger blood which suffers most—the fair, northern blood which nature attempts constantly to pour into the southern lands. If this be true, the effect of malaria will be constantly to resist the invigorating influx which nature has provided; and there are many facts in the history of India, Italy, and Africa which could be brought forward in support of this hypothesis.

"We now come face to face with that profoundly interesting subject, the political, economical, and historical significance of this great disease. We know that malaria must have existed in Greece ever since the time of Hippocrates, about 400 B. C. What effect has it had on the life of the country? In prehistoric times Greece was certainly peopled by successive waves of Aryan invaders from the north—probably a fair-haired people—who made it what it became, who conquered Persia and Egypt, and who created the sciences, arts, and philosophies which we are only developing further to-day. That race reached its climax of development at the time of Pericles. Those great and beautiful valleys were thickly peopled by a civilization which in some ways has not been excelled. Everywhere there were cities, temples, oracles, arts, philosophies, and a population vigorous and well trained in arms. Lake Kopais, now almost deserted, was surrounded by towns whose massive works remain to this day. Suddenly, however, a blight fell over all. Was it due to internecine conflict or to foreign conquest? Scarcely; for history shows that war burns and ravages, but does not annihilate. Thebes was thrice destroyed, but thrice rebuilt. Or was it due to some cause, entering furtively and gradually sapping away the energies of the race by attacking the rural population, by slaying the new-born infant, by seizing the rising generation, and especially by killing out the fair-haired descendant of the original settlers, leaving behind chiefly the more immunised and darker children of their captives, won by the sword from Asia and Africa? * * *

"I can not imagine Lake Kopais, in its present highly malarious condition, to have been thickly peopled by a vigorous race; nor, on looking at those wonderful figured tombstones at Athens, can I imagine that the healthy and powerful people represented upon them could have ever passed through the anæmic and splenomegalous infancy (to coin a word) caused by widespread malaria. Well, I venture only to suggest the hypothesis, and must leave it to scholars for confirmation or rejection. Of one thing I am confident, that causes such as malaria, dysentery, and intestinal entozoa must have modified history to a much greater extent than we conceive. Our historians and economists do not seem even to have considered the matter. It is true that they speak of epidemic diseases, but the endemic diseases are really those of the greatest importance. * * *

"The whole life of Greece must suffer from this weight, which crushes its rural energies. Where the children suffer so much, how can the country create that fresh blood which keeps a nation young? But for a hamlet here and there, those famous valleys are deserted. I saw from a spur of Helikon the sun setting upon Parnassus, Apollo sinking, as he was wont to do, towards his own fane at Delphi, and pouring a flood of light over the great Kopaik Plain. But it seemed that he was the only inhabitant of it. There was nothing there. 'Who,' said a rich Greek to me, 'would think of going to live in such a place as that?' I doubt much whether it is the Turk who has done all this. I think it is very largely the malaria."

In considering carefully this suggestive argument of Major Ross does it not appear to indicate the tremendous influence that the prevalence of endemic disease must exert upon the progress of modern nations, and does it not bring the thought that those nations that are most advanced in sanitary science and preventive medicine will, other things being equal, assume the lead in the world's work? Who can estimate the influence of the sanitary laws of the Hebrew scriptures upon the extraordinary persistence of that race through centuries of European oppression—centuries full of plague years and of terrible mortality from preventable disease? And what more striking example can be advanced of the effect of an enlightened and scientifically careful attention to the most recent advances of preventive medicine upon the progress of nations than the mortality statistics of the Japanese armies in the recent Russo-Japanese war as compared with the corresponding statistics for the British army during the Boer war immediately preceding, or for the American Army during the Spanish war at a somewhat earlier date?

The consideration of these elements of national progress has been neglected by historians, but they are nevertheless of deep-reaching importance and must attract immediate attention in this age of advanced civilization. The world has entered the historical age when national greatness and national decay will be based on physical rather than moral conditions, and it is vitally incumbent upon nations to use every possible effort and every possible means to check physical deterioration.

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FUMIGATION INVESTIGATIONS IN CALIFORNIA.

By R. S. WOGLUM,
Special Field Agent.

[CHEMICAL WORK PERFORMED BY THE MISCELLANEOUS DIVISION OF THE BUREAU OF CHEMISTRY.]

ISSUED JUNE 11, 1909.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1909.

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LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Bureau of Entomology,
Washington, D. C., February 6, 1909.

Sir: I have the honor to transmit herewith a manuscript entitled "Fumigation Investigations in California." It is a preliminary report on the subject, and contains much information which will be of direct practical value to citrus growers. The report is one of progress, and much of the information has already been made available to the public by means of lectures and field demonstrations, but it is important that it should be put in published form so as to give it wider currency. The subject is one that requires abundant illustration, and the figures and plates submitted are all deemed necessary for the full understanding of the text.

Respectfully,
L. O. Howard,
Entomologist and Chief of Bureau.

Hon. James Wilson,
Secretary of Agriculture.

PREFACE.

Fumigation under tents with hydrocyanic-acid gas has been the principal means of controlling scale-insects on citrus fruit trees in California for many years. Most of the commercial orchards in the State are fumigated at intervals of one or two years, at a cost ranging from 25 cents to $1.50 a tree, or a probable total annual expenditure of about $1,500,000, on the basis of fumigation of 50 per cent of the trees each year. It becomes, therefore, a matter of very great importance to conduct the operation of fumigation in the most effective and economical manner. The work being done on the subject in California by this Bureau is aimed to thoroughly standardize the process. It was undertaken in response to urgent demands from the horticultural commissioners of the principal citrus-fruit-producing counties of California, and of many prominent growers. The need of this investigation was most urgently championed by Mr. J. W. Jeffrey, former secretary of the Los Angeles County horticultural commission and now State commissioner of horticulture of California. Recognizing the general usefulness of the process of fumigation, Mr. Jeffrey called attention strongly to the unevenness of results in the work of different manipulators and against different scale pests, and that the whole practice had grown up experimentally without ever having been given thorough scientific examination. He urged that such an examination necessitated carefully conducted and recorded field work, supplemented by chemical tests of ingredients and the determination of reactions, and expert study of the physiological effect of the gas on the trees and fruit; in other words, to remove the process from the mere guesswork of the field man and to place it on an exact scientific basis.

This investigation has been under the direct charge of the writer, who made a personal study of the situation in southern California in September and October, 1907, and planned the work to cover the following subjects:

(1) Dosage, or the amount of gas and duration of exposure necessary for different purposes. The strength of gas necessary to effectively control the three prominent scale pests of citrus trees in California, namely, the red scale, the purple scale, and the black scale, under different climatic conditions, as in the drier foothills regions and

the moister coastal strip; for different seasons of the year; and for the different growing conditions of the tree, as whether in fresh leafage, or in bloom, or with different stages of the developing fruit.

(2) Physiological effect on the tree and fruit. There is some evidence to show that the gas may have a stimulating effect on the tree.

(3) Mechanical equipment. An important economical consideration in gassing is the employment of the most suitable tent cloths, and their treatment to give durability and imperviousness; also, the best mechanical means of hoisting tents over the trees. To be determined under this heading also are the most economical methods of generating the gas, and an indication of the quality of chemicals best suited for the purpose.

In connection with this experimental work the scale species themselves are being given a careful study in the field to determine their exact life history as a basis for the intelligent application of the remedy.

This investigation was started in July, 1907, under the field charge of Mr. R. S. Woglum, who first made himself thoroughly familiar with the problem by a personal examination of conditions throughout the citrus-growing regions of southern California. The direct work of investigation began as soon as the fumigation season opened, and later Mr. Frederick Maskew was employed to assist in the work. The experimental work as planned has been conducted on a commercial scale, so that the conditions and results will be those normal to the ordinary care of citrus groves. To carry out all the lines of experiment indicated above, and the subsidiary ones which have developed in the course of the investigation, takes a good deal of time, and will probably occupy two or three years with the money and force now available. Nevertheless, very considerable progress has been made, and the preliminary report herewith submitted covers the general features of fumigation procedure.

Improved methods have been devised, and these are being very rapidly adopted throughout southern California. These improved methods make it possible to do much more uniform work and greatly simplify the method of estimating the proper dosage. Full advantage has been taken of the fumigation work conducted in Florida against the white fly under the field direction of Dr. A. W. Morrill, and the Morrill system of marking tents for the ready determination of dosage has been introduced, with modifications, into California.

C. L. Marlatt,

Entomologist and Acting Chief of Bureau in Absence of Chief.

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INTRODUCTION.

Early in July, 1907, the writer received a commission to investigate the use of hydrocyanic-acid gas in the control of insect pests of citrus trees in southern California. Acting under detailed instructions from Mr. C. L. Marlatt, the Assistant Chief of the Bureau of Entomology of the United States Department of Agriculture, he spent the latter part of July and the following three months in a thorough field investigation to acquaint himself with the conditions of citrus culture throughout southern California, the distribution of the different citrus pests and the damage caused by them, the existing methods for their control, and the status of fumigation as then practiced in the various citrus districts. During this period all the important citrus-producing sections south of Santa Barbara were visited, and local conditions were carefully examined. This work was greatly facilitated by the hearty cooperation of the different county horticultural commissioners, who gave their time freely and greatly assisted the writer in becoming familiar with all the features of the problem in their respective counties.

The writer desires to acknowledge his indebtedness to the many people who have assisted him during this investigation and facilitated the progress which has been made. To Mr. C. L. Marlatt, Assistant Chief of the Bureau of Entomology, he is especially indebted for valuable assistance and advice. It is also the writer's great pleasure to acknowledge his appreciation of the work of Mr. Frederick Maskew, who has most capably assisted him in the performance of many of his experiments. Mr. Maskew also prepared several of the illustrations used. To the Hon. J. W. Jeffrey, State commissioner of horticulture of California, credit is due not only for his activity in paving the way for this investigation but also for the able support given since field work was commenced. To Mr. William Wood, of Whittier, Cal., the writer acknowledges his indebtedness for assistance in introducing the improved system of fumigation in the region adjacent to Whittier, as well as for practical advice with regard to citrus insects and their control, a subject about which he is especially well informed. This occasion is also taken to thank the various horticultural officers of southern California, packing-house managers, and the many citrus growers who have assisted and supported this investigation.

EXTENT OF CITRUS ORCHARDS.[a]

The production of citrus fruits in southern California is confined to the narrow stretch of land south and west of the Sierra Madre Range, extending from Santa Barbara on the north to the Mexican border. Although citrus plantings are located here and there throughout this territory, in reality only a small proportion of the land capable of cultivation is devoted to this industry. The most prominent centers of production (see fig. 1) are in the foothills region and lower land of the San Gabriel Valley; the corresponding regions of the San Bernardino Valley, including the Redlands-Highland, the Riverside, and the Corona districts; and the coast region of Orange

FIG. 1.—Map showing principal localities in southern California where citrus fruits are produced. (Original.)

and Los Angeles counties. Regions of smaller production are found in southern Santa Barbara and Ventura counties, in the San Fernando Valley, and in western San Diego County.

CITRUS PESTS.

INSECT ENEMIES OF CITRUS FRUITS, AND THEIR DISTRIBUTION.

The larger number of the pests most injurious to citrus fruits in southern California belong to the Coccidæ, a group of insects popularly known as scale-insects. Among the scale-insects which are

[a] For a general description of the California citrus-fruit industry, see Bulletin 123, Bureau of Plant Industry, United States Department of Agriculture, which may be obtained for 20 cents from the Superintendent of Documents, Government Printing Office, Washington, D. C.

generally so destructive as to require extended efforts for their control are the purple scale (*Lepidosaphes beckii* Newm.), the red scale (*Chrysomphalus aurantii* Mask.), and the black scale (*Saissetia oleæ* Bern.). The yellow scale (*Chrysomphalus citrinus* Coq.), considered a variety of the red scale, is much less destructive generally, though sufficiently troublesome in some localities to be considered a pest of primary importance. Other scale-insects attacking citrus trees, which are so perfectly held in control by their natural enemies and other causes as seldom to become very destructive, are the soft brown scale (*Coccus hesperidum* L.), the hemispherical scale (*Saissetia hemisphærica* Targ.), the oleander scale (*Aspidiotus hederæ* Val.),

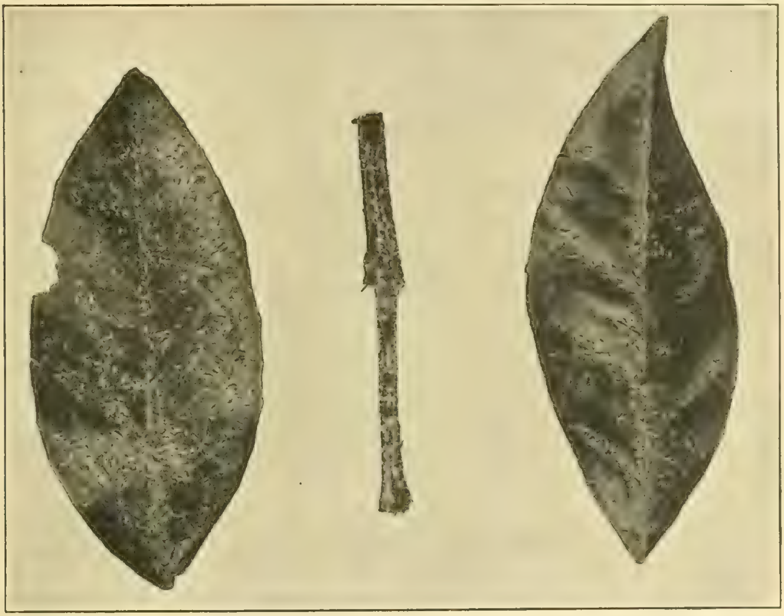

FIG. 2.—Leaves and branch of orange infested with purple scale (*Lepidosaphes beckii*). (Original.)

and the cottony cushion scale (*Icerya purchasi* Mask.). Mealy bugs (*Pseudococcus* spp.) are quite generally prevalent.

The most important pests other than scale-insects are to be found among the mites, of which the rust mite of the orange or silver mite of the lemon (*Phyllocoptes oleivorus* Ashm.) and the citrus red spider (*Tetranychus mytilaspidis* Riley) are highly injurious. The orange aphis (*Aphis gossypii* Glov.) becomes very numerous during some seasons but is soon attacked by its natural enemies and held in control. A species of thrips worked quite extensively in some localities on ripe oranges during the first months of 1908, removing the coloring matter from beneath the epidermis, thus giving to the fruit a spotted appearance which lowered its market grade.

The purple scale (figs. 2 and 3) appears to prefer the more moist regions in the vicinity of the ocean. It is found in Santa Barbara and Ventura counties; in Los Angeles County, inward from the coast as far as Hollywood and Whittier, and in the lower part of the San Gabriel Valley at Covina and Duarte; throughout Orange County; and in San Diego County in the region about San Diego city. This insect confines its attack to citrus trees.

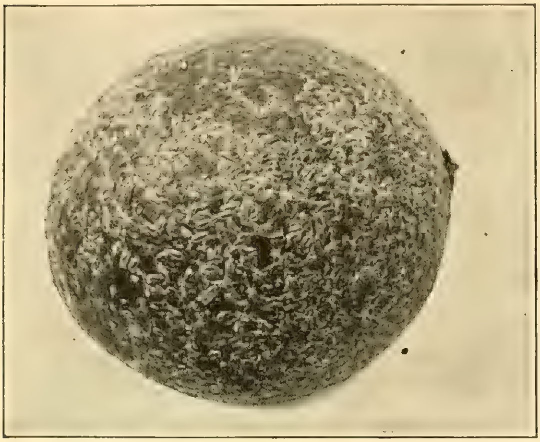

FIG. 3.—Fruit of orange infested with purple scale. (Original.)

The black scale (fig. 4) is also considered as partial to the more moist regions, and without doubt is able to mature more freely here than in the hot interior country. It is distributed, however, throughout the citrus-growing localities with the exception of the Rialto-Highland-Redlands region of San Bernardino County. At Redlands this scale is found on olives and some ornamental plants; yet, to the best of the writer's knowledge, it has not been reported from citrus orchards. Even as far inland as Ontario and Riverside the black scale is capable of breeding freely during some parts of the year, but the hot days of summer destroy a large percentage of the eggs and especially those young scales which are exposed to the sun's rays. This destruction was especially noticeable in the summer season of 1907, when the writer was engaged in an examination of different localities. During the first part of July occurred a few days of very hot weather. About

FIG. 4.—Branches of orange infested with black scale (*Saissetia oleæ*). (Original.)

a month later inspections were made throughout the lower San Gabriel Valley, at Pomona, Ontario, and Riverside, and in Orange County. Throughout this valley a large majority of the young insects which had hatched were dead at this time while fully 50 per cent of the eggs had dried up. At Pomona, Ontario, and Riverside almost all the young insects had been destroyed, and fully 90 per cent of the eggs beneath the old scales. In Orange County near the coast a very small percentage of eggs was affected by this hot period, while recently hatched young scales were much in evidence. The black scale occurs on a wide range of hosts, including trees, shrubs, and herbaceous plants.

The red scale (fig. 5) thrives exceedingly well in the drier interior regions of southern California. It can be found within a few miles

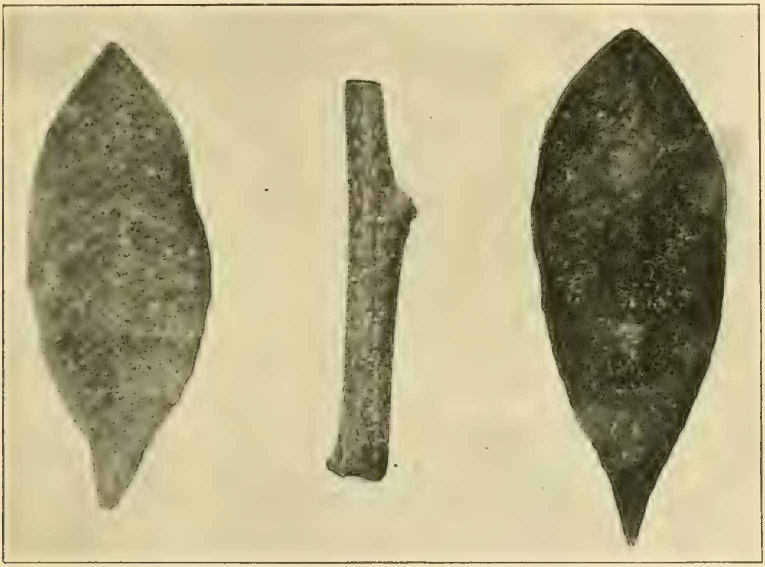

FIG. 5.—Leaves and branch of orange infested with red scale (*Chrysomphalus aurantii*). (Original.)

of the ocean or as far inland as Redlands. The limits of its distribution are much the same as for the black scale. This species can be found on several host plants other than citrus species.

The yellow scale is even more of a heat-withstanding form than the red scale. Infestation by this insect appears to be most marked in the foothills region of the San Gabriel Valley, and along the Sierra Madre Range through Upland and Cucamonga. It is also broadly distributed at Redlands, where it has become a more serious menace than elsewhere in southern California. That it is capable of withstanding excessive heat is demonstrated by its prevalence in citrus orchards in the San Joaquin Valley, at Marysville, Oroville, and other parts of the hot interior valleys of northern California, where the purple scale and to a large extent the black scale appear unable to survive.

Mealy bugs occur in various parts of the southern end of the State. Their appearance is usually spasmodic and in restricted areas. These insects are at present more serious than elsewhere in Ventura County, where they occur in great numbers.

The citrus red spider is general in distribution, whereas the silver mite is restricted to the region about the city of San Diego.

INJURY RESULTING TO SCALE-INFESTED TREES.

In scale insects the mouth is an elongated beak or tube. This tube is inserted into the bark or covering of the host plant when the insect is feeding, and is used to draw up the plant juices, which are the scale-insect's only food. When great numbers of these insects draw sap from the tree, even though they are very minute, the tree's vitality is greatly reduced. This effect is very marked in the attacks of the red and purple scales. Both of these species cause much destruction, yet the writer is of the opinion that the red scale will destroy a citrus tree in less time than will the purple scale, all other factors being equal. Trees have been noticed from two to three years after planting which had been killed by the red scale. Large orchard trees are frequently destroyed by the pest (fig. 6), while it is a very common sight in regions of severe infestation to see large branches killed back to the trunk. Although no trees have ever come to the writer's attention which were completely killed by the purple scale, severe infestations result in the destruction of many branches (fig. 7), and cause such a drain on the tree that the production of fruit is greatly decreased. Moreover, the purple scale spreads

FIG. 6.—Orange tree almost destroyed by red scale. (Original.)

to the fruit, as does also the red scale, resulting in expense for the cleaning of fruit or rendering it of a lower grade and, in extreme cases, entirely valueless.

The black scale, although a much larger insect than either the red scale or purple scale, appears to have, generally, little effect on the vitality of the tree. Trees severely infested with the black scale may appear as healthy as neighboring trees which are clean. Branches are seldom if ever destroyed by its attacks alone.

The commercial importance of the black scale arises largely from its habit of secreting honeydew, which spreads over the leaves, fruit,

FIG. 7.—Orange tree showing branches at center partly destroyed and stripped of leaves by purple scale (*Lepidosaphes beckii*). (Original.)

and branches, furnishing a growing medium for a black or sooty-mold fungus, resulting in a black coating throughout the tree. This coating is removed from the fruit by washing, or in light attacks by brushing. In the investigation by Mr. G. Harold Powell[a] of the causes of decay of oranges while in transit from California, it was shown that the decay was greater in washed than in unwashed fruit. To avoid the washing of fruit it is necessary to destroy the scale in the orchards.

[a] Bul. 123, Bur. Plant Industry, U. S. Dept. of Agriculture, 1908.

The black scale confines its attack mainly to the branches, yet it is commonly found on the leaves during its earlier stages of development and sometimes matures in this situation. Seldom does it mature on the fruit. The red and purple scales infest the branches, leaves, and fruit. The yellow scale occurs on the leaves and fruit. Occasionally it is found to a very slight extent on the branches.

The more directly injurious effect to the tree resulting from the attacks of the red, purple, and yellow scales appears to the writer to be due to their ability to produce some toxic effect in the host plant in addition to the injury caused by the removal of sap. These scales cause a discoloration of the plant cells at the place where the sap is extracted, whereas the larger black scale causes no discoloration whatever.

METHOD OF PROPAGATION OF THE MORE INJURIOUS SCALE PESTS.

The young purple and black scale-insects hatch from eggs deposited by the adult, while the red and yellow scales produce their young alive. The red and yellow scales are thus susceptible to the application of remedial measures at any time throughout the year. The eggs of the purple scale are much more difficult to destroy than the insects, for the latter can be killed readily in any stage of development although more easily in the early stages. The black scale is capable, after it has reached its mature and leathery condition, of resisting extreme insecticidal applications. Its eggs, also, are quite as resistant as the mature insect, if not more so. In its early stages, however, it can be readily destroyed by the proper insecticides.

In all species the different broods on citrus trees are seldom, if ever, distinct, but overlap one another to varying degrees. At certain periods the breeding is more marked than at others for each of these insects; yet it is possible to find adult red, yellow, purple, or black scales in the egg-laying stage at any time throughout the year in any extensive citrus locality in southern California containing thrifty trees and in which these scales are known to thrive. This overlapping of broods is due largely to the forcing and artificial conditions of citrus culture.

METHODS USED IN THE CONTROL OF SCALE PESTS OF CITRUS TREES.

The methods generally resorted to in the control of citrus insect pests are (1) fumigation, (2) spraying, and (3) the use of beneficial insects.

The question of beneficial insects is too large for discussion in this limited report; suffice it to say that their work is of the highest importance in many respects.

Sulphur sprays are employed against the red spider and the silver mite of the lemon.

Distillate sprays have been employed by southern California horticulturists for many years, and at one time very extensively in the control of citrus scales. The accumulated experience with these sprays appears to have demonstrated that the results secured are not entirely satisfactory. To-day distillate sprays are used only on a small acreage of citrus groves, having been supplanted by the more satisfactory fumigation with hydrocyanic-acid gas. Nothing illustrates more distinctly the superiority of fumigation over spraying with distillate oils than the readoption of fumigation by the more successful citrus growers, and the attitude of the officials of the county horticultural commissions of this region who, almost to a man, now recommend fumigation for the control of scale-insects.

A kerosene-water spray has found a limited use during the past year in Riverside and Ventura counties.

FUMIGATION.

Fumigation with hydrocyanic-acid gas originated and was first practiced in California by Mr. D. W. Coquillett, of the Bureau of Entomology, in 1886, in combating citrus insect pests. Since that time it has gradually risen in favor as a means of destroying scale enemies of citrus plants until to-day it is in use in almost all the important citrus-producing countries of the world. The apparatus first used in fumigation was somewhat complicated and cumbersome, making the operation very expensive.[a] As the use of this gas became more widespread a gradual improvement in equipment as well as methods has taken place, so that to-day the process is comparatively simple.

SHEET TENTS.

Sheet tents exclusively are now used in southern California. The manipulation of sheet tents and the general procedure in fumigation have been so clearly explained in Bulletin No. 76 of this Bureau that it will not be necessary to devote space to them here. The tents are octagonal in shape, the standard sizes being 17, 24, 30, 36, 41, 43, 45, 48, 52, 55, and 64 feet, but larger ones up to 72 or 84 feet have been employed. The size of this style tent is properly based on the distance between the parallel sides, not on the distance between opposite corners.

The materials especially recommended, and now generally used for fumigation tents in southern California, are 6½-ounce special drill and 8-ounce special army duck, although 10-ounce special army duck is sometimes used in very large tents. The 6½-ounce special drill is made of single threads twisted hard and closely woven. It is light, strong, and flexible. The special army duck is made of double

[a] See Ann. Rept. U. S. Dept. Agr. for 1887, p. 123, 1888.

threads twisted hard and woven fairly close. This double-twisted material is heavier and much stronger than the special drill, but not so closely woven; consequently it is somewhat more porous. In field work the special drill will adapt itself more closely to the irregularities of the ground than the army duck, and particularly if the tents become damp. The special 6½-ounce drill is generally considered the best obtainable for use in all fumigation tents up to 45 feet standard size. Special 8-ounce army duck is recommended for use in tents of larger size. Probably the most satisfactory method of making large tents is to have the center of special duck and the sides of special drill. This distributes the heavy material at the points of greatest wear, while the drill makes the tent much lighter and more flexible.

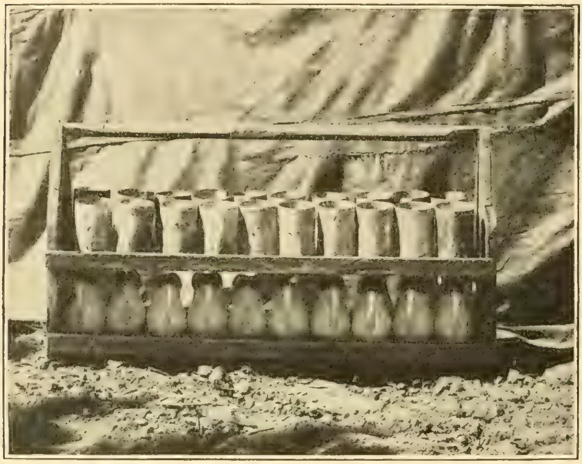

FIG. 8.—Tray commonly used for carrying the chemicals of fumigation from tree to tree. Cans above contain cyanid; pitchers below contain acid. (Original.)

POINTS ON PROCEDURE.

The number of men making up an outfit varies from three to six. In San Bernardino County most of the outfits consist of six men; elsewhere they more commonly consist of four.

In estimating the dosage, the usual method is to make the estimate before the trees are covered with a tent. Sometimes this scheduling is done in the daytime, sometimes by night. The schedule for a row of trees to be fumigated having been given, either one of two methods of procedure is followed. In the first and more common method the dosage of cyanid and acid for each tree of the row is measured out into small cans and pitchers, which are placed in a tray after the manner shown in figure 8. When ready for use this tray is carried from one tree to the next down the row (fig. 9). Frequently two trays are necessary to carry the material required for the entire row or set of trees. The water is carried in a pail and measured at each tree. The receptacles in which the gas is generated consist of earthenware jars holding 1½ to 2 gallons, having the handle on the side (fig. 10). If dosages in excess of 16 ounces are used in a 1½-gallon generator or in excess of 20 ounces in a 2-gallon generator, the contents will frequently boil over, especially if the cyanid is in small lumps or is powdered.

DOSAGE SCHEDULES OF THE MORE IMPORTANT WRITERS ON FUMIGATION.

Since the publication by Morse, in 1887, of the first dosage schedule for use in fumigating citrus trees with hydrocyanic-acid gas, a great many tables of dosage have been recommended through publications in this country and abroad. Among the more authoritative contributions on this subject are those of Coquillett, Morse, Craw, Marlatt, Johnson, Havens, Woodworth, Pease, and Morrill, of this country; C. P. Lounsbury, of South Africa, and W. J. Allen, of New South Wales. A careful study has been made of the dosage schedules proposed by these different investigators with a result most surprising. In the first place, we must consider that uniform dosage will not be given to trees unless based directly on their cubic contents when covered with a tent. Secondly, dosage tables prepared for trees merely with regard to their cubic contents and without regard to the varying proportions of leakage surface present in trees of different sizes are faulty to a large degree. Of all the dosage tables which have come to the writer's attention only those by Lounsbury, in South Africa, by Morrill, in Florida, and a recent one by Woodworth in California, have been based on the proper assumptions. The other tables were either based directly on the cubic contents without regard to leakage surface, or were prepared without any knowledge whatever of the cubic contents represented by trees of given dimensions. Several

FIG. 9.—Man carrying tray and water bucket. (Original.)

belong to the latter class. The following statement and comparative table have been prepared which indicate the wide range of variation in these schedules:

Dosage schedules.—For the information of those who may be inclined to doubt the writer's contentions in this bulletin with relation to the generally chaotic condition of fumigation schedules published in the interests of California citrus growers, a table has been prepared which includes nearly all of the more important schedules, together with a comparative analysis of the same. The dosages for trees of given dimensions were duly computed. Having this data at hand and utilizing the dosage allotted to each individual tree, it was possible to work out the rate of

FIG. 10.—A typical California lemon orchard with row of fumigation generators placed ready for use the following night. (Original.)

dosage per 100 cubic feet of inclosed space at which that particular tree was being fumigated. This has been done for all trees in the schedules proposed by several writers, and the results have been arranged in the latter half of the table.

A glance at this table will show that the schedules of Morse, Coquillett, and Woodworth were all based on the cubic contents of the trees, which were dosed at a uniform rate, but without regard to the leakage of gas. Large trees are dosed at the same rate as small ones, thus giving a lack of uniformity in results. All of the other schedules detailed in this table were apparently prepared with little or no regard to the cubic contents represented by trees of different dimensions. Although it would appear from the table that leakage was taken into account, inasmuch as the smaller trees receive a greater rate than the larger ones, proper allowance could not be made for this factor without definite consideration of the cubic contents. Consequently the decrease of rate recommended is in all cases irregular and widely removed from a rate proportionate to the actual leakage. The fact that trees increase in dimensions much more rapidly than in cubic contents is seldom taken into consideration. The result is that the larger trees receive a relatively smaller dosage than they should.

Morse's schedule was prepared especially for the cottony cushion scale and probably for the red scale. The schedules of Coquillett and Pease, and doubtless that of Craw, were prepared for the red scale. Those of Johnson, Woodworth, the Riverside Commission, and the Rural Californian were intended especially for use against the black scale. The red scale was generally known to be harder to destroy than the black scale.

In Morse's schedule all trees receive practically three-fourths ounce per 100 cubic feet of inclosed tent space; in Coquillett's, practically one-half ounce to 100 cubic feet; in Woodworth's schedule they receive one-third ounce for the same space. In Craw's table, the smallest tree receives approximately 9 times as great a dosage rate as the largest; in Johnson's table, the smallest receives about 4½ times the rate of the largest; in that of the Riverside Commission, the smallest is allowed about 13 times that of the largest; in that of the Rural Californian, the smallest receives about 8 times that of the largest; while in that of Pease, the smallest receives a dosage rate about 14½ times as great as the largest tree.

This short analysis seems sufficient to call attention to the irregularities of these schedules. A study of the following table will reveal many other interesting points.

Dosage schedules recommended by several recognized authorities, with computed dosage rates per 100 cubic feet of space inclosed by tent.

AMOUNT OF CYANID (OUNCES) PER TREE RECOMMENDED.

Height of tree.	Width of tree.	Cubic contents of tree.	Morse.[a]	Coquillett.[b]	Craw.[c]	T. B. Johnson.[d]	Woodworth.[e]	Riverside Horticultural Commission.[f]	Rural Californian.[g]	Pease.[h]
Feet.	*Feet.*	*Cubic ft.*	*Ounces.*	*Ounces.*	*Ounces.*	*Ounces.*	*Ounces.*	*Ounces.*	*Ounces.*	*Ounces.*
4	4	40	0.3							
4	5	60								4
5	5	80	.6							
6	4	70			1	1		1	½	
6	5	100								4
6	6	140	1				½			5
7	7	225	1.6							
8	5⅓	160					½			
8	6	200			2	2		1½	1¼	5
8	8	335	2.4				1			7
9	9	475	3.4							
10	6⅔	310					1			
10	8	435		2¼	3	3½		2½	2	7
10	10	645	4.6			4½	2			8
11	11	870	6.2							
12	8	535					2			
12	10	800		4½	5	5			4½	8
12	12	1,130	8				4			10
12	14	1,490		8¾	7	7		5	4½	
13	13	1,440	10.2							
14	10	960		5½						
14	12	1,355		7½		7				10
14	14	1,790	12.4		8	8			5	12
15	10	1,036					4			
15	15	2,210	15.7				8			
16	14	2,105		12		9				12
16	16	2,680	19		9	10⅓		8	5½	14
17	17	3,215	23							
18	14	2,400		15						
18	16	3,080			10				6	14
18	18	3,815	27.1							
19	19	4,470	28.3				16			
20	13⅓	2,475					8			
20	16	3,485			11	13		10	6½	
20	18	4,325				15		14		
20	20	5,235	36.2					10		
20	22	6,210						14		
22	18	4,835			12				7¼	

[a] Bul. 71, Univ. of Cal. Agr. Exp. Sta. (1887).
[b] Insect Life (1889).
[c] Destructive Insects (1891).
[d] Cal. State Bd. of Horticulture (1896).
[e] Bul. 115, Univ. of Cal. Agr. Exp. Sta. (1896).
[f] Farmers' Bul. 127, U. S. Dept. Agric.
[g] From "Fumigation Methods," by W. G. Johnson.
[h] California Cultivator (1908).

Dosage schedules recommended by several recognized authorities, with computed dosage rates per 100 cubic feet of space inclosed by tent—Continued.

AMOUNT OF CYANID (OUNCES) PER TREE RECOMMENDED—Continued.

Height of tree.	Width of tree.	Cubic contents of tree.	Morse.	Coquillett.	Craw.	T. B. Johnson.	Woodworth.	Riverside Horticultural Commission.	Rural Californian.	Pease.
Feet.	*Feet.*	*Cubic ft.*	*Ounces.*	*Ounces.*	*Ounces.*	*Ounces.*	*Ounces.*	*Ounces.*	*Ounces.*	*Ounces.*
24	18	5,340				18		14		
24	20	6,490			13	20		16	8	
24	22	7,735						14		
24	28	11,900						16		
26	20	7,120			13½				8¼	
30	20	8,375			14			16	8½	
30	25	12,680						24		
30	28	14,365						16		
30	30	16,675						24		
36	25	15,630						24		
36	30	21,915						24		

COMPUTED DOSAGE RATE (OUNCES OF CYANID) PER 100 CUBIC FEET OF INCLOSED SPACE.

Height of tree.	Width of tree.	Cubic contents of tree.	Morse.	Coquillett.	Craw.	T. B. Johnson.	Woodworth.	Riverside Horticultural Commission.	Rural Californian.	Pease.
Feet.	*Feet.*	*Cubic ft.*	*Ounces.*	*Ounces.*	*Ounces.*	*Ounces.*	*Ounces.*	*Ounces.*	*Ounces.*	*Ounces.*
4	4	40	0.75							
4	5	60								6.6
5	5	80	.75							
6	4	70			1.4	1.4		1.4	0.77	
6	5	100								4
6	6	140	.72				0.36			3.6
7	7	225	.71							
8	5⅓	160					.31			
8	6	200			1	1		.75	.63	2.5
8	8	335	.72				.3			2.1
9	9	475	.72							
10	6⅔	310					.32			
10	8	435		0.50	.76	.8		.57	.46	1.6
10	10	645	.72			.7	.31			1.25
11	11	870	.7							
12	8	535					.37			
12	10	800		.56	.62	.62			.56	1
12	12	1,130	.71				.35			.88
12	14	1,490		.58	.57	.47		.33	.3	
13	13	1,440	.71							
14	10	960		.58						
14	12	1,355		.56		.51				.74
14	14	1,790	.7		.45	.45			.28	.67
15	10	1,036					.38			
15	15	2,210	.71				.36			
16	14	2,105		.57		.43				.57
16	16	2,680	.71		.34	.38		.3	.21	52
17	17	3,215	.71							
18	14	2,400								
18	16	3,080			.32				.2	.45
18	18	3,815	.71							
19	19	4,470	.63				.36			
20	13⅓	2,475					.32			
20	16	3,485			.31	.37		.29	.19	
20	18	4,325				.35		.32		
20	20	5,235	.78					.19		
20	22	6,210						.22		
22	18	4,835			.25				.15	
24	18	5,340				.34		.26		
24	20	6,490			.20	.31		.25	.12	
24	22	7,735						.18		
24	28	11,900						.13		
26	20	7,120			.19				.12	
30	20	8,375			.17			.19	.1	
30	25	12,680						.19		
30	28	14,365						.11		
30	30	16,675						.14		
36	25	15,630						.15		
36	30	21,915						.11		

THE PRESENT SYSTEM OF SCHEDULING DOSAGE.

When we understand that up to the present time only one approximately accurate dosage schedule has been proposed by the fumigation experts of California, and, what is more confusing, that no two tables agree in all respects, we can not wonder that the practical fumigator has turned from them in perplexity. Finding the tables of little assistance, the fumigator has had to determine his own dosage from practical experience and the results secured. If he failed to destroy the scale on a 6-foot tree in using 1 ounce of cyanid, he increased his dosage for the next 6-foot tree, and so on. He has also learned that the dosage required to destroy some scales is greater than that for other species. Under the system at present in vogue the dosage is usually estimated in the daytime. The estimator, who ordinarily is the man in charge of the outfit, starts out in an orchard equipped with cross-section paper or a schedule sheet. He walks between two rows of trees, jotting down in the corresponding squares of the schedule sheet the dosage which he believes the trees should receive. If he is a careful scheduler he will look at the trees from different sides before indicating the dosage, as trees are sometimes more compact on one side than on another. Less careful men set down the dosage for the two rows of trees while moving along as fast as they can walk. The writer has seen some schedulers walk through the field at a rapid pace, taking four rows at a time.

The estimation of dosage in this manner is mainly guesswork. Measurements of the trees are made by the eye; consequently, successful results depend very largely upon the accuracy of the estimator's eye-measurement, supported by his experience in fumigation. The most careful of estimators are very irregular in their scheduling. This point has already been mentioned by Professor Woodworth.[a] From measurements taken after many fumigators, we have found none who did not at times vary more than 50 per cent in dosage estimates for trees containing exactly the same cubic contents after being covered with a tent. Frequently the variation is as high as 100 per cent. The results secured by a few of the more careful and expert schedulers have been good as a whole. These men, however, can cover but a small portion of the citrus groves of southern California in one season.

The writer has been shown orchards in which it was stated that all the scale had been destroyed by the use of heavy dosages. Even if this were the case it would show that the smallest percentage or strength of dosage used on any tree in those orchards was sufficiently large to destroy the scale. Since, as we have found, expert fumigators

[a] Bul. 152, Univ. of Cal. Agr. Exp. Sta., 1903.

vary considerably in their estimates, many trees in the above-mentioned orchards must have received a much greater dosage than was necessary for scale eradication, thus resulting in a waste of cyanid and acid.

In Table I have been arranged the dosage estimates which were scheduled in different orchards by three different fumigators. After the trees had been covered with tents the exact contents were computed by the writer from actual measurements. The dosages given in these tables are not for scattered individual trees selected because of their irregularity in size, but each table embraces a continuous number in a single row taken at random, regardless of the size or regularity of the trees. As great a lack of uniformity as that shown in each table might be looked for throughout the orchard. These schedules of dosage were used against the red and purple scales, species considered by most fumigators to be about equally resistant to the gas. The reader will note the wide difference in the dosage in the estimates of the different fumigators.

TABLE I.—*Variation in the dosages estimated for several consecutive trees by three different fumigators.*

Work of first fumigator.			Work of second fumigator.			Work of third fumigator.		
Dosage recommended.	Actual volume of treated tree.	Volume of space in tent to each ounce of dosage.	Dosage recommended.	Actual volume of treated tree.	Volume of space in tent to each ounce of dosage.	Dosage recommended.	Actual volume of treated tree.	Volume of space in tent to each ounce of dosage.
Ounces.	*Cubic feet.*	*Cubic feet.*	*Ounces.*	*Cubic feet.*	*Cubic feet.*	*Ounces.*	*Cubic feet.*	*Cubic feet.*
11	1,690	150	11	1,000	90	6	1,500	250
12	2,050	170	7	400	60	4	1,100	275
10	1,369	135	15	1,800	120	4	800	200
10	1,663	165	10	600	60	5	1,200	240
10	1,516	150	16	2,200	140	4	1,100	275
12	1,440	120	15	1,800	120	4	900	225
12	1,663	140	16	2,400	150	5	1,300	260
12	1,755	145	16	2,000	125	5	1,150	230
12	1,350	110	18	2,200	120	5	950	190
9	1,175	130	17	2,200	130	4	950	238
....	....	....	12	1,250	105	5	900	180
....	....	....	16	2,500	156	6	1,550	258

THE INITIAL PROBLEM CONFRONTING THIS INVESTIGATION.

After becoming acquainted with the existing methods of fumigation, it was realized that one of the first problems to be solved was to devise some accurate system of determining dosage which would obviate the errors due to guesswork. It at once became apparent that the only way in which this result could be attained was by determining accurately the cubic contents of the space inclosed by the tent and giving the tree a dose proportionate to the contents. It was also apparent that before such a system could be put into operation, after having been worked out in practice, it would be necessary to determine by an extensive series of experiments the dosage required for different-sized trees for the various scale pests infesting the citrus orchards.

METHOD OF COMPUTING VOLUME AND DOSAGE FOR TENTED TREES.

Although most citrus trees possess a certain general similarity in shape, they are nevertheless somewhat irregular, no two ever being identical in all respects. This renders it impracticable to determine the exact contents of any given tree. For field work, however, this is unnecessary, and all that is needed is to approximate it with a fair degree of accuracy. In order to calculate the cubic contents of an object, it must be considered as shaped like some regular geometrical figure or figures. The figure which most closely approximates in shape an orange or lemon tree before it has been pruned is a cylinder surmounted by a hemisphere, and in computing the volume we have considered them of this shape.

If we know the height and width of a tree covered with a tent, it is a comparatively simple matter to calculate its contents.

In the past in California work the dosage has been based upon these two measurements. After a tree is covered with a tent it is a matter of some difficulty to determine the height and the width. By using as factors the distance around the bottom of the tent and the longest distance over the top of the tent we arrive at a more practicable method by which to compute the cubic contents of a given tree. Using these measurements as a basis the writer has invented a formula [a] by means of which the cubic contents of a tree may be computed. To avoid computation work in the field as far as possible, the writer has formulated a table approximating the cubic contents of trees of different dimensions, which is, he believes, sufficiently extensive to include any citrus tree in southern California. During this investigation no tree has been found whose dimensions did not fall within the limits given in this table. The distance

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[a] Professor Woodworth (Bul. 152, Univ. of Cal. Agr. Exp. Sta., p. 5, 1903) was the first to propose a formula for obtaining the contents of tented trees by computing the distance around the bottom and over the top. An analysis of this formula during the early part of the writer's field work proved that it was inaccurate, thus necessitating the determination of a new formula. The writer has worked out a formula based on the two measurements above mentioned. It is as follows:

$$\frac{C^2}{4\pi}\left(\frac{O}{2}-\frac{C(3\pi-4)}{12\pi}\right)$$

In this formula C=the circumference of the tree.

O=the distance over the top of the tree.

If a person works out and notes down in a chart the values of $\frac{C^2}{4\pi}$ and $\frac{C(3\pi-4)}{12\pi}$ for different values of C of which he is apt to make common use, it is possible by its use in connection with the formula to determine the contents of trees with fair rapidity.

around and over a given tree being known, the table will show the approximate cubic contents of the tented tree. The dosage can then be applied in proportion to the contents and at any strength desired.

A lemon tree, after being pruned, is flat on the top. Therefore we can not consider the geometrical figure which is applicable to an orange or unpruned lemon tree as also applicable to a pruned or flat-topped lemon tree. The figure which approximates the latter is a cylinder. Now it so happens that the contents of a cylinder having certain dimensions over its top and around its bottom are almost the same as for a figure of the same dimensions composed of a cylinder surmounted by a hemisphere. This is a great advantage inasmuch as the schedule of dosage proposed for orange trees may also be used for all lemon trees, thus obviating the necessity of preparing two different schedules.

METHODS FOR OBTAINING THE MEASUREMENTS AND DOSAGE OF TREES.

WITH APPARATUS.

Of the various methods suggested for obtaining the measurements of tented trees, the first was naturally by the use of a tapeline. It was an easy matter to ascertain the distance around the tent with a tape, but to measure the distance over the top was much more difficult. This required the services of two men and repeated efforts. For field work on a commercial scale this was impracticable.

Woodworth[a] explains a method of securing measurements, which consists in the use of a fishing rod and a wire line, the latter marked off by knots into 1-meter lengths. His description of this method is as follows:

> Having first attached the line at about its middle to the end of the rod, one end of the former is made fast to the tent. The most convenient way to accomplish this was found to be by means of a hook, like a fishhook from which the barb had been removed. The most convenient place of attachment was at a point 1 meter from the ground.
>
> After attaching one end of the line to the tent the rest of that half is caused to lie up to and over the center and top of the tent by means of the rod. The one making the measurement then walks around to the opposite side of the tent, rod in hand, holding the line constantly in position over the top. The other end of the line is carried around the tent at the same time and is then drawn taut, measuring the last fraction of a meter by means of the graduation on the lower joint of the rod. Adding now 1 meter, the distance the first end is from the ground, we have the measurement of the distance over the top of the tent from the ground on one side to the ground on the other.
>
> A second measurement was then taken by throwing the line off the top of the tent by means of the rod and holding it so that as the measurer proceeds around the tent to the point where the line is attached, it will encircle the tent at a point about 1 meter from the ground. The end of the rod is again brought into requisition and the last fraction of meter read in centimeters.
>
> Both measurements are thus made by one person in a single trip around the tent.

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[a] Bul. 152, Univ. of Cal. Agr. Exp. Sta., 1903.

This method might be practicable with a medium-sized tree, but for trees of large size, especially seedlings, which are sometimes more than 30 feet in height, its use would doubtless prove difficult, and for field operations multiplication of apparatus should be avoided as far as possible.

WITHOUT APPARATUS.

The Woodworth system.—The first scheme, so far as the writer's knowledge goes, for obtaining the measurements and dosage of trees without the use of apparatus was suggested by Professor Woodworth.[a] This method consists of marking on the tent, on two opposite sides and parallel with the edge, a series of lines which are placed at such distances from the center of the tent that they will correspond with differences of 1 ounce in the dosage of trees of the average shape. Upon each of these lines are marked three numbers; the first indicating the dose (in ounces), the second the circumference on which the dose is based, and the third the amount the dose must be varied when the actual measured circumference is greater or less than that marked on the tent. For trees having a circumference greater than the average between the second figure on the line that is nearest the ground on one side of the tent and the second figure on the corresponding line on the opposite side, the average dose is increased for each additional yard of circumference by the amount (in ounces) given by the third figure on the line; for trees having smaller circumferences the figures are correspondingly decreased.

Although the system is fairly accurate, its adaptability for use under the present condition of fumigation in southern California is somewhat questionable. The amount of calculation required to ascertain the dosage for each tree gives large chance of error and is wasteful of time. The possibility of error is still further increased through the necessity of varying the dosage for different species of scale-insects.

The Morrill system.[b]—Dr. A. W. Morrill, in the course of his work against the white fly (*Aleyrodes citri* R. & H.) in Florida, has devised a method of marking tents which is easily the most practicable yet proposed for obtaining the distance over the top of a tented tree. Although apparently a modification of the idea presented in the Woodworth method, it is really quite different. In the Woodworth system the actual dosage is calculated from the figures on the tent. The Morrill system is merely a rapid and simple way of obtaining the distance over the top of a tented tree.

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[a] Bul. 152, Univ. of Cal. Agr. Exp. Sta., 1903.

[b] Bul. 76, Bur. Ent. U. S. Dept. Agr., 1908.

In figure 11 is shown an outline of a regulation fumigating tent marked after the Morrill system. Three parallel lines and one line at right angles to them are indicated on the tent. The middle one of the three parallel lines passes through the central point in the tent canvas, running lengthwise of the central section or strip of which the tent is made and passing over the top of the tent from the edge on one side to the edge on the opposite side; these lines

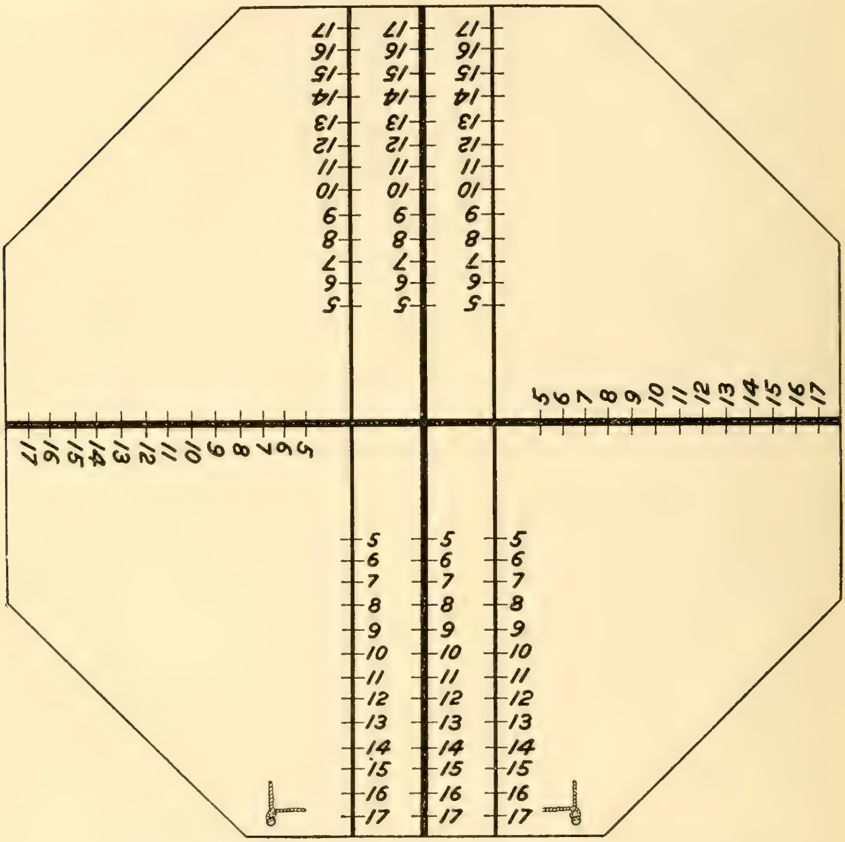

FIG. 11.—Outline of a fumigation tent marked according to the Morrill system.

also run in the direction in which the tent should be pulled on or off a tree. The single line at right angles to the parallel lines passes through the central point, as does the middle one of the three parallel lines, and extends also from the edge on one side to the edge on the opposite side. Beginning at the center these lines are graduated in feet toward either edge of the tent, after the manner shown in the diagram. For tents above 36 feet (average size) it is unnecessary to commence the graduation nearer than 5 feet from the center of the canvas. When one of these lines is over the middle of the tree (fig. 12), the distance over can be calculated by merely adding together the two numbers on the opposite sides of the tent where the edge touches the ground. For instance, suppose that on the line over the center of the tree 12 is nearest the ground on one side and 15 on the other. The distance over the center of this tree would be the sum of these numbers, which is 27 feet. With the lines graduated after this manner it makes little difference in determining the distance over the top of the tree whether or not the geometrical center of the tent is at the center of the tree, the single requirement being that some part of one of the graduated lines approximates the center of the tree.

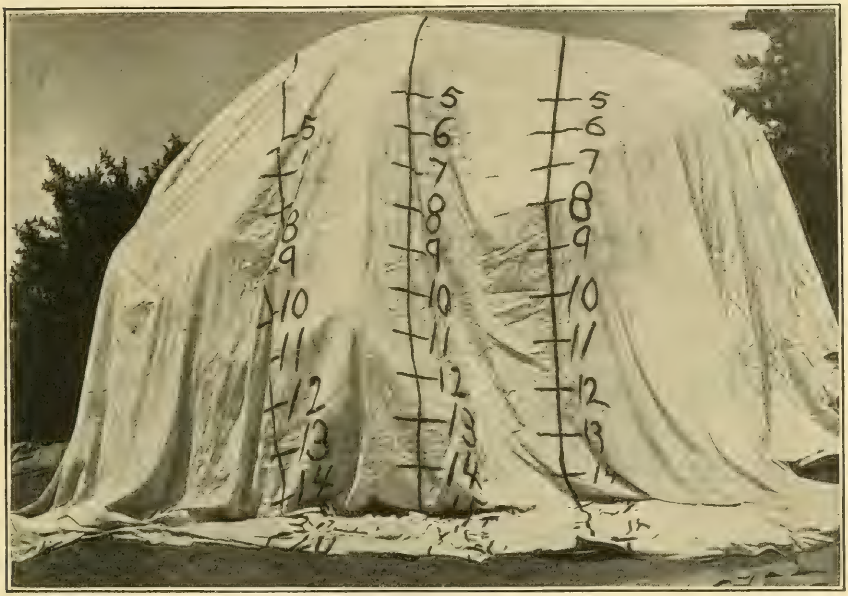

FIG. 12.—A fumigation tent marked after the Morrill system. (Original.)

The two lines running parallel to this central line should be about 4 feet distant from it in the larger fumigating tents. The reason for using these auxiliary lines is, that in practice the center of the tent is very often pulled considerably to one side, especially in covering small trees. If the middle line does not fall immediately over the center of the tree, one of the other two lines is quite likely to do so, and that one should be used in obtaining the distance over.

The cross line running at right angles to the three parallel lines also passes through the center of the tent and is marked like the others. In case of an irregularly shaped tree, by the use of this line the distance over can be taken in two different directions and the average taken for use in determining the cubic contents. In field work, however, this cross line is unnecessary, as measurement over the top in one direction is sufficient.

The measurement around the bottom of the tent can be obtained by the use of a tapeline or by pacing. Under this system the work is facilitated by having a chart or table of figures showing the cubic contents corresponding to different dimensions.

THE CHEMICALS REQUIRED IN FUMIGATION.

For the generation of hydrocyanic-acid gas in fumigating, potassium cyanid, sulphuric acid, and water are necessary. The hydrocyanic-acid gas is produced by the action of the sulphuric acid on the cyanid of potassium. Under the early methods of generating hydrocyanic-acid gas the cyanid was dissolved in water before being used. At the present time cyanid is used in the crystal form entirely. The water is first measured out and poured into the generating vessel. The required amount of acid is then added to the water, producing a great increase in the temperature of the mixture. While the mixture is hot it should be placed beneath the tree and the cyanid added. If permitted to cool before the cyanid is added, the generation of gas will not only be slower than with the heated mixture, but the amount of available gas will be decreased, thus making the operation more expensive, and necessarily less efficient.

POTASSIUM CYANID.

An imported cyanid designated as 98 to 99 per cent pure is used almost exclusively for fumigation purposes in southern California, under the popular belief that it is superior to American cyanids for this purpose. There seems to be no real basis for this common belief, and, in fact, experiments conducted by Prof. Wilmon Newell while State entomologist of Georgia demonstrated that certain brands of American cyanid met all the requirements necessary for fumigating nursery stock, and it seems reasonable to believe that these will also be equally available for citrus-orchard fumigation. A series of laboratory and field tests has been planned to demonstrate the usefulness of all the available brands of potassium cyanid.

In the field investigation reported in this bulletin the 98 to 99 per cent imported cyanid commonly used in southern California has been employed throughout and, although no chemical analysis was made, the results proved entirely satisfactory.

SULPHURIC ACID.

Too much stress can not be placed upon the quality of sulphuric acid used in fumigation. Operators have repeatedly informed the writer of much burning of fruit and foliage which occurred during the season of 1905, owing to the use of a grade of acid differing from that ordinarily employed. An analysis of the acid used that season showed that it contained traces of nitric acid, the presence of which might explain the burning. Nitric acid is one of the most active of chemicals and is unstable as well. When heated it readily volatilizes. By adding sulphuric acid to water a great amount of heat results. If nitric acid be present in the sulphuric acid as an impurity it would be far more volatile than under ordinary circumstances. The addition of the cyanid increases the heat, at the same time causing hydrocyanic-acid gas to be violently thrown off. This gas assists in carrying off the volatilized nitric acid, which, condensing on the cool, moist surfaces presented by the fruit and leaves of the citrus trees, might result in burns or pits.

In procuring sulphuric acid for fumigating purposes, only that should be purchased which is entirely free of nitric acid, and which is guaranteed 66° (Baumé), or 93 per cent pure.

Some commercial sulphuric acid on the market meets all the requirements of fumigation, while much can be found which does not. To enter fully into the reason for this would be out of place in this bulletin. All that is necessary is to mention briefly the character of the material and processes used by various manufacturers, some of whom strive to place a better grade of acid on the market than do many others.

In the manufacture of sulphuric acid, sulphur may be considered the basic element. This is obtained from one of two sources, viz, from free sulphur, known commercially as brimstone, or from sulphur in combination with a metal, as iron or copper pyrites. Brimstone is comparatively pure sulphur, containing little or nothing which would reduce the grade of the acid manufactured from it. It sometimes contains a very small quantity of ash. Pure iron pyrites contains about 53 per cent of sulphur and about 47 per cent of iron. Copper pyrites contains much less sulphur. Ordinarily the pyrites used in making acid contains small quantities of other elements, as arsenic, zinc, lead, etc. To manufacture sulphuric acid, it is necessary to convert the sulphur into a gas, sulphur dioxid, which is brought about by burning the crude product in a retort. The sulphur dioxid thus formed is conducted into certain chambers where it is mixed with fumes of nitric acid, air, and steam, the resulting product being dilute sulphuric acid. Where brimstone is used comparatively pure sulphuric acid is formed. When, however, pyrites are burned, other elements present in the ore (as arsenic, etc.) are volatilized, pass along with the sulphur dioxid, and are present in the crude acid.

That which concerns us most vitally in fumigating is the presence of nitric acid. A much greater proportion of nitric acid becomes mixed with the products of combustion from pyrites than from brimstone, resulting in the presence of a larger amount of this undesirable acid in the sulphuric acid. The impurities, including nitric acid, may be eliminated by refining. This, however, requires extra expense, and, as these impurities are of little or no importance in some of the lower uses to which sulphuric acid is put, the acid is not usually refined. Such acid is unsuitable for use in fumigation.

Taking all things into consideration it is safer, in purchasing ordinary commercial sulphuric acid on the market, to order that made from brimstone rather than that made from pyrites ore. It is possible, however, to secure quite as good a product from pyrites as from brimstone, if the former be sufficiently refined. If the fumigator demands that it be free from nitric acid, arsenic, etc., and refuses to accept it unless the product is of the grade required, there is no reason why he should not be able to secure satisfactory material.

PROPORTION OF MATERIALS USED BY FUMIGATORS.

With each dry ounce of potassium cyanid most fumigators use 1 fluid ounce of sulphuric acid, although some use 1¼ ounces. The proportion of water used varies all the way from 2 to 8 times the amount (by bulk) of acid, the majority using between 3 and 4 parts of water.

THE AMOUNT OF SULPHURIC ACID NECESSARY.

Chemical combinations take place with definiteness; that is, when one chemical acts on another in the production of a third substance, the proportion between the first two chemicals is always the same. Such is the case when sulphuric acid acts upon potassium cyanid in producing hydrocyanic-acid gas. A given amount of cyanid requires a certain amount of sulphuric acid of a fixed degree of purity to carry the reaction to completion. A quotation from a letter received from J. K. Haywood, of the Bureau of Chemistry of this Department, illustrates this point:

> In the action of sulphuric acid on potassium cyanid approximately four-fifths of an ounce (avoirdupois) of 93 per cent acid is used up for every ounce of 98 per cent cyanid.[a]
>
> Expressed in fluid ounces four-fifths of an ounce avoirdupois equals about 0.42 of a fluid ounce. We may say that theoretically 1 ounce avoirdupois of 98 per cent potassium cyanid needs 0.42 of a fluid ounce of ordinary commercial sulphuric acid (93 per cent) to convert it entirely to hydrocyanic acid. Since it is always best to have some excess of the acid to carry the reaction to completion, it is probable that three-fourths of a fluid ounce of commercial sulphuric acid is ample in practice to convert 1 ounce avoirdupois of 98 per cent potassium cyanid to hydrocyanic acid. If 1 fluid ounce of the commercial sulphuric acid is used it will certainly leave a con-

[a] The reaction is as follows:

$$2KCN + H_2SO_4 = K_2SO_4 + 2HCN.$$

siderable excess of sulphuric acid present. It is perfectly possible, however, that this excess of sulphuric acid is of value in heating up the mixture so that more of the hydrocyanic acid is liberated and not absorbed by the liquid.[a]

The results of some tests serve as a further illustration of this point. It was desired to determine by experiment if 1 fluid ounce of acid to each ounce (avoirdupois) of cyanid would be sufficient to carry the reaction to completion in the liberation of hydrocyanic-acid gas. It is to be understood throughout that the cyanid ounce is avoirdupois and the acid and water is the fluid ounce. For this test two series of ordinary 1½-gallon fumigating vessels were placed in line. In one series equal parts of acid and cyanid were used. Three parts of water were used in all cases. The amounts of cyanid used ranged from 1 to 10 ounces, that is, in one generator were placed 1 ounce of cyanid, 1 ounce of sulphuric acid, and 3 ounces of water; in the next of the same series, 2 ounces of cyanid, 2 ounces of sulphuric acid, and 6 ounces of water, and so on in the same proportion up to 10 ounces. The second series was identical with the first except for the use of one-fourth more acid than cyanid. After generation had taken place for about one and one-half hours an examination was made of the residue. In the first series, in which equal parts of acid and cyanid were used, the residue was in the form of a liquid. In the second series, in which 1¼ ounces of acid to 1 of cyanid were used, the residue in several pots had collected in a mushlike mass. Being puzzled at first over this phenomenon, in order to ascertain if cyanid still remained unchanged in the residue the writer added more sulphuric acid, but there was no further evolution of gas. This at once demonstrated that all the available cyanid had been dissolved. Analyses of this residue by J. K. Haywood of the Bureau of Chemistry showed that the reaction was complete both when 1 ounce of acid and when 1¼ ounces of acid to 1 of cyanid were used. In submitting the result of these analyses, Dr. H. W. Wiley, Chief of the Bureau of Chemistry, wrote:

> The amount of cyanid present in these samples is so small that it does not indicate to us incompleteness of reaction, but rather indicates the amount of hydrocyanic acid dissolved in the residue. This view of the case is strengthened by the fact that increasing the amount of sulphuric acid in the cases above did not decrease the amount of cyanogen present in the residue. From our work, therefore, we are of the opinion that the same amount of sulphuric acid as of potassium cyanid is sufficient to carry the reaction to completion.

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[a] In an address printed in the Proceedings of the Thirty-fourth Annual Fruit Growers' Convention of California, p. 103, the proportion of chemicals spoken of appears somewhat different from that mentioned in this publication. This is due to the fact that the parts mentioned in that address were based on parts by weight of acid and cyanid, both of which are chemically pure—not the commercial product as given in this bulletin.

Summing up, it may be said that 1 fluid ounce of commercial sulphuric acid (93 per cent) to 1 ounce (avoirdupois) of 98 per cent potassium cyanid is certainly enough to carry the reaction to completion in the liberation of hydrocyanic-acid gas and is perhaps an unnecessarily large amount. In practical field work where dosages of varying sizes are constantly being used, it is very convenient to reckon the acid in the same number of parts as the cyanid. The use of 1 part (fluid measure) of acid to each part of cyanid is therefore recommended.

The commercial potassium cyanid sold on the market is usually 96 to 100 per cent pure. The commercial sulphuric acid on the market is sold as 66° Baumé and should contain 93.5 per cent sulphuric acid. In California fumigation work, these grades are used and are to be understood wherever cyanid or acid is mentioned in this bulletin. In the dosage allotments cyanid is always measured in ounces or parts dry weight, while the acid is measured in fluid ounces or parts.

THE EFFECT OF TOO GREAT AN EXCESS OF ACID.

In the experiment mentioned, in which two series of hydrocyanic-acid gas generations were completed, the question immediately arose, why the residue in some generators, in which 1¼ parts of acid were used, congealed, while in the case of those in which equal parts of acid and cyanid were used no such result was noted. The explanation is simple: When sulphuric acid acts on potassium cyanid, hydrocyanic acid, a gas, and potassium sulphate, a solid, are formed. If sufficient water is present, the potassium sulphate dissolves and there is no solid residue. This was the result when equal parts of acid and cyanid were used. When one-fourth more acid than cyanid is employed, there is a large excess of acid. The potassium sulphate is not as soluble in water containing excess acid as it is in water alone; hence it undergoes partial crystallization, resulting in a mushlike residue or congealing into a solid mass.

WATER AS A FACTOR IN FUMIGATION.

There are several reasons why water should always be employed in fumigation: It is very useful in dissolving the potassium cyanid and hastening and completing the chemical reaction with the acid. A piece of cyanid thrown into a mixture of acid and water immediately gives up a portion of its mass in solution. Scarcely has the cyanid dissolved when it is partially converted into gas. The heat liberated during this process assists in forcing the solution of more cyanid, which is also partially converted into gas. This continues until the chemicals are exhausted and the reaction stops.

Potassium sulphate, a solid, is the by-product resulting from the reaction by which hydrocyanic-acid gas is produced. Water dissolves the potassium sulphate as it forms and prevents it from coating the cyanid not yet in solution. In the presence of an insufficient amount of water, the potassium sulphate is not completely dissolved, but forms a coating on the pieces of cyanid, preventing the sulphuric acid from penetrating to it, and thereby retarding, or even in part preventing, the reaction. In such cases this undissolved potassium sulphate usually congeals, causing the pots to "freeze." The phenomenon always occurs where the formula is 1–1–1, or where the same amounts of water, acid, and cyanid are used. On agitating the congealed residue by stirring, it is almost always possible to find small pieces of undissolved cyanid enveloped in a coating of the potassium sulphate. Ordinarily, when the residue is stirred the particles of cyanid are removed, to some extent, from this envelope of potassium sulphate, allowing some of the unused acid to reach them, and thus evolving a small amount of gas without the addition of more acid. Under these conditions, however, the reaction is never complete, and it is highly desirable therefore to add sufficient water at the beginning to dissolve all the potassium sulphate.

From this last statement, as well as the data presented under the heading "The effect of too great an excess of acid" (p. 34), it is seen that the congealing or "freezing" of generating jars is due to either or both of two conditions: (1) An insufficient amount of water to completely dissolve the sulphate of potassium, or (2) a large excess of sulphuric acid, whereby the water is rendered less capable of taking into solution the same amount of sulphate as it otherwise would.

Another very important function of the water in the reaction is the heat produced by the union of the sulphuric acid and water. Potassium cyanid introduced into this heated mixture gives off hydrocyanic-acid gas much more quickly and thoroughly than at a lower temperature, and in field work rapid generation of gas is essential.

THE EFFECT OF DIFFERENT PROPORTIONS OF WATER ON THE TEMPERATURE OF THE GAS.

Anyone who has watched the escaping gas and steam from the reaction of potassium cyanid and sulphuric acid wherein different proportions of water were used could not fail to notice that the violence with which the generation starts and the gas is given off is apparently greatest with the smaller proportions of water. Fumigators are aware of this, and commonly increase the proportion of water when using large amounts of cyanid. Practice has demonstrated that with a greater proportion of water the injurious effect of the resulting gas on the leaves and fruit is materially lessened. The lessening of the injury has been attributed to the fact that the escaping gas was less heated when large proportions of water were used. In order to clear up this point an experiment was performed, the results of which are given in Table II.

Table II.—*Experiment to determine the effect of different proportions of water on the temperature of the resulting gas.*

Amount of chemicals used.			Temperature of the acid and water mixture.	Highest temperature of the hydrocyanic-acid gas.	Temperature of the gas one minute from start of generation.
Cyanid.	Acid.	Water.			
Ounces.	*Ounces.*	*Ounces.*	°*F.*	°*F.*	°*F.*
5	5	5	180	124	115
5	5	10	190	126	121
5	5	15	170	128	109
5	5	20	160	128	105
5	5	25	145	118	105
5	5	30	136	108	104
5	5	40	125	90	87

In this experiment 5 ounces (avoirdupois) of cyanid and 5 ounces (fluid) of acid were used for each test. The proportions of water were varied, 5, 10, 15, 20, 25, 30, and 40 ounces, respectively, being used. As a result the proportion of water to 1 part of acid or 1 part of cyanid was 1, 2, 3, 4, 5, 6, and 8, respectively, for the different tests. These generations were made in a 1½-gallon fumigating vessel in a room. The temperature of the escaping gas was taken at the mouth of the pot. The temperature of the acid-water mixture was taken one minute after pouring the two together. The cyanid was then added.

The maximum temperature of the escaping gas is always realized within the first minute, usually thirty to forty seconds after the generation commences. Examination of the maximum temperature of the gas as noted in the third column of the table above indicates that the temperature of the gas is reduced when large proportions of water are used. When using from 1 to 4 parts of water, the temperature is nearly uniform, but with 5 parts of water the decrease becomes marked. Repetitions of the above experiment gave similar results. The violence of the reaction and the temperature of the gas are affected more or less by the size of the pieces of cyanid. A very violent reaction results from the use of cyanid in powdered form.

We would expect that to increase the proportion of water would decrease the temperature of the gas. One reason is shown in this table under the column marked "Temperature of the acid and water mixture." As the proportion of water to sulphuric acid becomes larger the resulting temperature of the mixture is lessened. Hence when the cyanid is added to the mixture as high a degree of heat to start the reaction is not developed as when the smaller proportion of water is used, and in consequence gas is evolved less violently.

THE TEMPERATURE OF THE GAS WHERE LARGE AND SMALL DOSAGES ARE USED.

In an experiment to determine the temperature of the gas resulting from large and small dosages (Table III) the chemicals were used in the following proportions: Cyanid 1 part, acid 1 part, and water

3 parts. The reactions were accomplished in 2-gallon earthenware fumigating vessels in a room where the air was moderately quiet. The temperature of the gas was taken at the mouth of the vessels.

TABLE III.—*Experiment to determine the temperature of the gas resulting from large and small dosages.*

Amount of chemicals used.			Highest temperature of mixture of acid and water.	Time after mixing when temperature of mixture is highest.	Temperature of mixture at end of one minute.	Highest temperature of hydrocyanic-acid gas.	Time after generation when temperature of gas is highest.	Temperature of gas one minute from generation.	Temperature of gas two minutes from generation.
Cyanid.	Acid.	Water.							
Ounces.	*Ounces.*	*Ounces.*	*°F.*	*Seconds.*	*°F.*	*°F.*	*Seconds.*	*°F.*	*°F.*
3	3	9	135	30	131	100	30	83	73
6	6	18	163	35	157	130	30	104	86
8	8	24	167	25	160	135	30	106	92
10	10	30	170	25	164	132	30	103	90
12	12	36	164	30	157	140	30	113	95
14	14	42	178	25	173	145	25	116	98
16	16	48	173	25	161	152	25	118	99
20	20	60	172	25	168	153	25	123	106

An examination of this table shows that the temperature of the escaping gas increases somewhat as the dosages become larger. Hence if heated gas is more injurious than cooler gas, we would expect more burning as a result of the increased dosages. This is exactly what does happen to some extent in field operations. It is interesting to note that the highest temperature of the acid-water mixture occurs about one-half minute after the mixing takes place. The highest temperature of the hydrocyanic-acid gas occurs about one-half minute after the generation commences, and then the temperature of the gas rapidly decreases during two to two and one-half minutes, at the end of which time most of the gas has been evolved. At the expiration of from three to five minutes the generation of gas has practically ceased.

THE EFFECT OF DIFFERENT PROPORTIONS OF WATER ON THE AMOUNT OF AVAILABLE HYDROCYANIC-ACID GAS.

In the course of this investigation an experiment was made to determine the amount of hydrocyanic-acid gas available when generated with different proportions of water. The results as determined by the Bureau of Chemistry of this Department are given in the accompanying chart (fig. 13).

In these experiments commercial sulphuric acid, 66° Baumé or 92.77 per cent pure, and potassium cyanid 97.12 per cent pure were used. Three ounces (fluid) of sulphuric acid and 3 ounces (avoirdupois) of potassium cyanid were employed in each experiment, and 3, 6, 9, 12, 15, 18, 21, and 24 ounces, respectively, of water were used in the different experiments.

From the following chart it is evident that with the acid and cyanid mentioned the largest amount of gas is available from two parts of water. As the proportion of water is increased above two parts the avaliable gas is decreased until with eight parts of water we obtain only about 43 per cent of gas, or less than one-half as much as with two parts. In other words, 1 ounce of cyanid and 1 ounce of acid in combination with 2 ounces of water will produce much more available gas than 2 ounces of cyanid and 2 ounces of acid with 16 ounces of water.

The cause for the smaller amount of gas with one part of water than with two parts has already been explained (see p. 35).

We can see from the chart that the proportion of water used is one of the most important factors in fumigation practice; and many of

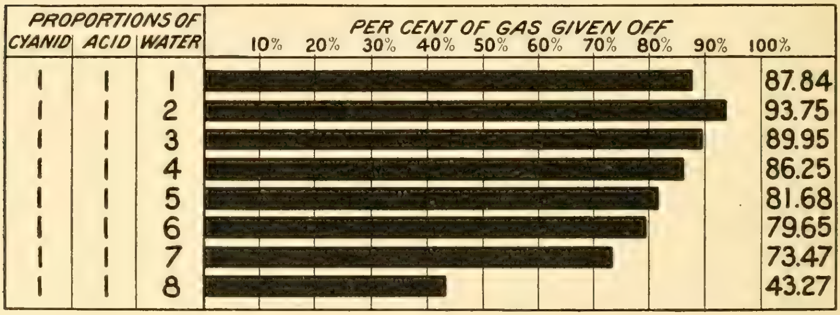

FIG. 13.—Chart showing total amount of gas evolved when different proportions of water are used. (Original.)

the poor results in field work can be directly attributed to the use of too much water. That the water should be measured as carefully as the acid is beyond question.

Aside from variations in the amount of water used, due to lack of precision in measuring, the proportion of water recommended by different authorities on fumigation has varied all the way from two to eight parts. It is no wonder we see widely differing results from the work of different men. It is a common practice with many fumigators to increase the dosage when fumigating a tree that is severely infested with scale. It is also a common practice—in fact, so common as to be almost universal—to increase the proportion of water when using heavy dosages. This is apparently done with a view to preventing injury to the fruit and foliage. In following out this practice the fumigator has many times unconsciously prevented the very result he wished to accomplish—that of obtaining a more concentrated gas.

THE CORRECT PROPORTION OF WATER.

The chart (fig. 13) shows that two parts of water to one part each of cyanid and acid will produce the maximum amount of available gas. It is impracticable, however, to use two parts of water in field work, for with this proportion of water the residue, especially where small dosages of powdered cyanid are used, will frequently congeal within an hour's time—the usual period for leaving the tents on the trees. Although this proportion of water is apparently sufficient to dissolve the sulphate at first so that a complete reaction takes place, it appears unable to hold the sulphate in solution long enough afterwards to prevent inconvenience in field work. It is of course evident that a "frozen" generator does not always signify an unsatisfactory generation. With three parts of water, however, the residue seldom congeals, and this is the proportion we have used in all of our field work and which we recommend. The water should be measured carefully with a glass or dipper graduated to ounces.

THE MOST ECONOMICAL PROPORTION OF CHEMICALS TO USE IN GENERATING HYDROCYANIC-ACID GAS.

In the preceding discussion it has been shown that for various reasons 1 fluid ounce of commercial sulphuric acid and 1 ounce (avoirdupois) 96 to 100 per cent potassium cyanid in combination with 3 fluid ounces of water give a complete reaction. Thus the 1–1–3 formula, hitherto recommended by the Bureau of Entomology, is fully indorsed.

A review of the use of hydrocyanic-acid gas for fumigation, both in California and elsewhere, shows frequent divergence from the more economical and satisfactory proportion of chemicals indicated above. One book recognized as an authority on fumigation methods recommends the use of "one-half more acid than cyanid and one-half more water than acid." Many of the entomologists and horticulturists in the eastern United States advise in their recommendations for nursery fumigation two parts of acid and four parts of water to each part of cyanid.

MIXING THE CHEMICALS.

It is preferable to pour the water into the generator first and then add the acid. The pouring of the water onto the acid is more likely to cause splashing of the acid from the jar onto the fumigator. When the acid and water are in readiness for generating the gas the fumigator adds the pieces of cyanid to the mixture and hastily retreats. As already stated, the cyanid should be added while the mixture of water and acid is hot. The advantage of this is shown in the following experiments performed by the Bureau of Chemistry of this Department. One ounce of potassium cyanid, 1 fluid ounce of commercial sulphuric acid, and 3 fluid ounces of water were used in each case.

Experiment No. 1.—The potassium cyanid was added to a mixture of acid and water in which the heat was exhausted, and it was found that 23.25 per cent of hydrocyanic acid remained in solution and was not liberated.

Experiment No. 2.—The potassium cyanid was added to a mixture of acid and water when first combined, i. e., when the heat was great, and it was found that only 10.68 per cent of hydrocyanic acid remained in solution.

CAUTION.—The cyanid should never be placed in the water before the acid is added. If the acid is added to the cyanid in solution, a very violent reaction takes place, which will sometimes throw much of the liquid from the vessel. In one instance about 1 pound of cyanid was dissolved in water in a 2-gallon generator. Acid was then added, producing a disturbance so violent as to throw some of the liquid almost to the top of a two-story barn.

A 1½-gallon generator will serve for a dose of about 15 ounces of cyanid without boiling over, or a 2-gallon generator for approximately 20 ounces.

The residue from the reaction contains more or less sulphuric acid which has not been used. This residue should never be deposited against or at the base of a tree, as it may penetrate to the roots, especially in light sandy soils, destroying a part if not the entire tree.

PURPLE SCALE FUMIGATION.

PRELIMINARY EXPERIMENTS FOR THE CONTROL OF THE PURPLE SCALE.

During the month of November, 1907, experiments were undertaken at Orange, Cal., to determine the dosage required for the destruction of the purple scale (*Lepidosaphes beckii* Newm.) in all its stages, as well as to determine the effect of exposures of different durations. The orchard under treatment contained orange trees varying from 7 to 14 feet in height. The infestation with the purple scale was very severe on many of the trees.

In the first experiment the duration of exposure was thirty minutes. In this experiment a series of tests was made to determine the effect of different dosages. These tests were as follows: One series of trees was dosed at the rate of three-fourths ounce of cyanid per 100 cubic feet of inclosed space; a second series at the rate of 1 ounce, a third at the rate of 1¼ ounces, and so on, increasing the dosage of each succeeding series at the rate of one-fourth ounce per 100 cubic feet. The largest dosage used was 2½ ounces per 100 cubic feet.

The second and third experiments were the exact counterparts of the first in all respects except that the duration of the exposures was respectively one hour and one and one-half hours.

From the data secured from these experiments it should be possible to determine the killing dosage for the purple scale for that particular length of time, provided a sufficient strength of gas was reached. To insure that the dosage sought would fall within the scope of the schedule, the limits were made very broad. From the difference in strength of killing dosage between these three experiments we would be able to determine the effect of length of exposure on results secured.

To obviate as much as possible the leakage of gas, which would vary in trees of different sizes, trees were chosen of as uniform a size as could be obtained. The cubic contents of the trees chosen for the first two experiments did not vary greatly and the trees ranged between 11 and 14 feet in height. As in the first two experiments most of the larger trees had been used, for the third experiment we were compelled to utilize those remaining, which varied somewhat in size, and were also, for the most part, noticeably smaller than those represented in the first two experiments.

During the latter part of January an examination was made of the results of these experiments. Fully two weeks were devoted to this, and thousands of the purple scale were scrutinized. The method employed was a very careful one. In each case the scales were overturned and examined with a powerful hand lens. In those instances in which the entire contents of the scale were not at once revealed, the delicate ventral scale was ruptured and the contents scraped out. Through this method not a single egg could escape observation.

Four trees were used in each test and an examination to determine results was made of each. This examination included many infested leaves and branches taken as close to the ground as possible and up to 6 or 7 feet above the ground. Infested fruit was also examined when obtainable. The average condition existing in these four trees was taken to indicate the result of the test.

The chemicals were used in the following proportion: Potassium cyanid, 1 part; sulphuric acid, 1 part; water, 3 parts.

TABLE IV.—*Fumigation for the purple scale, experiment No. 1.*

[Length of exposure, thirty minutes; height of trees, 11 to 14 feet.]

Number of trees treated.	Cyanid per 100 cubic feet of space.	On leaves and branches.		On fruit.	
		Insects alive, approximately.	Eggs normal, approximately.	Insects alive, approximately.	Eggs normal, approximately.
	Ounces.	*Per cent.*	*Per cent.*	*Per cent.*	
4	$\frac{3}{4}$	5-6	Over 75.	10	Fully 90 per cent.
4	1	0	About 75.	2	Many normal eggs found under every scale containing eggs.
4	$1\frac{1}{4}$	0	15-20	0	Some normal eggs found under almost every scale containing eggs.
4	$1\frac{1}{2}$	0	2-3	0	15 per cent.
4	$1\frac{3}{4}$	0	Less than 1.	0	5-7 per cent.
4	2	0	0	0	1 per cent.
4	$2\frac{1}{4}$	0	0	0	Two instances of apparently normal eggs.
4	$2\frac{1}{2}$	0	0	0	None.

In this experiment, when three-fourths of an ounce of cyanid per 100 cubic feet of space was used, live adult females were found on the leaves and branches, but the insects were killed by all greater dosages; normal eggs were found after the use of a dosage as high as 1¾ ounces per 100 cubic feet. Live insects were found on the fruit after both the three-fourths-ounce and 1-ounce tests, but were destroyed by the heavier dosages; normal eggs were found on the fruit after dosages up to and including the 2¼-ounce rate; with 2½ ounces per 100 cubic feet, all were apparently destroyed.

This experiment indicates that for normally shaped orange trees, from 11 to 14 feet in height, situated in a region with conditions comparable to those at Orange, and exposed to the gas for thirty minutes, a dosage of about 2 ounces per 100 cubic feet is required for eradication of the purple scale from the leaves and branches. If the trees contain fruit infested with scale, it is necessary to increase the dosage rate to 2½ ounces to accomplish the same result.

TABLE V.—*Fumigation for the purple scale, experiment No. 2.*

[Length of exposure, one hour; height of trees, 11 to 14 feet.]

Number of trees treated.	Cyanid per 100 cubic feet of space.	On leaves and branches.		On fruit.	
		Insects alive, approximately.	Eggs normal, approximately.	Insects alive, approximately.	Eggs normal.
	Ounces.				
4	¾	0	1–5 per cent.	0	Many instances.
4	1	0	1 per cent or less.	0	Several instances.
4	1¼	0	2 doubtful cases.	(a)	(a)
4	1½	0	0	0	One doubtful case.
4	1¾	0	0	0	Few instances of normal eggs on one fruit.
4	2	0	0	0	No instances of normal eggs.
4	2¼	0	0	(a)	(a)
4	2½	0	0	(a)	(a)

[a] No infested fruit on these trees.

With an exposure of one hour all insects were destroyed on the leaves and branches at a three-fourths ounce dosage rate. All eggs were destroyed at the 1½-ounce dosage rate. Since very few oranges infested with scale were found on the trees used in this experiment, it is considered that further investigation will be necessary before the effect of different dosages on scale infesting the fruit is definitely known. No live insects were found infesting the small amount of fruit available. Normal eggs were found after a dosage as high as the 1¾-ounce rate.

This experiment would lead to the conclusion that for normally shaped orange trees, from 11 to 14 feet in height, exposed to the gas for one hour, and situated in a region with conditions comparable to those at Orange, a dosage rate of 1½ ounces per 100 cubic feet will destroy the purple scale in all its stages on the leaves and wood. If the tree contain fruit infested with this scale it will be necessary to slightly increase the dosage. The exact amount of this increase can not be stated with accuracy at this time, owing to the fact that in the single experiment performed very little infested fruit from which data might be secured was available.

TABLE VI.—*Fumigation for the purple scale, experiment No. 3.*

[Length of exposure, one and one-half hours; size of trees mostly 7 to 10 feet; occasionally one 11 or 12 feet.]

Number of trees treated.	Cyanid per 100 cubic feet of space.	On leaves and branches.		On fruit.	
		Insects alive, approximately.	Eggs normal, approximately.	Insects alive, approximately.	Eggs normal.
	Ounces.				
4	$\frac{3}{4}$	3-5 per cent.	40-50 per cent.	10-15 per cent.	Above 75 per cent.
4	1	1 live female.	20-25 per cent.	1-2 per cent.	65-75 per cent.
4	$1\frac{1}{4}$	0	4-5 per cent.	(a)	(a)
4	$1\frac{1}{2}$	0	1-2 per cent.	0	Two oranges examined; many normal eggs present.
4	$1\frac{3}{4}$	0	3 instances of normal eggs.	0	A few normal eggs.
4	2	0	0	(a)	(a)
4	$2\frac{1}{4}$	0	0	(a)	(a)
4	$2\frac{1}{2}$	0	0	(a)	(a)

[a] No material for examination.

In this experiment live insects were found on the branches and leaves in the cases where three-fourths ounce and 1-ounce dosages were employed. Normal eggs were found up to and including the $1\frac{3}{4}$-ounce rate, but were destroyed by dosages exceeding this. As in the case of experiment No. 2, so little scaly fruit was available at that time that we are inclined to consider the results in this part of the test as yet incomplete.

THE LEAKAGE OF GAS IN FUMIGATING SMALL TREES.

When the results of experiment No. 3 are compared with those of experiment No. 2 we are at first led to believe that an error has been made. In experiment No. 2 it was found that the $1\frac{1}{2}$-ounce dosage rate destroyed all insects and eggs on the leaves and branches, whereas in this experiment it required one-half ounce more cyanid per 100 cubic feet, or a 2-ounce dosage rate, to accomplish the same result. Since the period of exposure was thirty minutes longer than that of experiment No. 2, we would naturally expect that the results accomplished would be as good or better, all other conditions being the same. The apparatus and chemicals employed were identical in both cases; and the conditions under which the fumigation was conducted were practically the same. There was, however, one difference: The trees involved in the one and one-half hour fumigation were much smaller than those of the one-hour test. This fact accounts for the less satisfactory results in eradicating the scale, in this experiment. We know that a leakage of gas takes place through the tent and that more gas will escape through 2 square feet of cloth than through 1 square foot in a given time. It will be shown in one of the following discussions that the leakage surface of tented trees is proportionately much greater for smaller trees than for larger ones. This would lead us to expect a greater escape of gas and consequently the requirement of a heavier dosage rate with the smaller than with the larger trees. The last experiment demonstrated the correctness of this deduction.

THE LENGTH OF EXPOSURE.

All considerations were the same in experiments Nos. 1 and 2 except the length of exposure. In using a 2-ounce dosage rate, we were able to destroy the purple scale in all of its stages on the leaves and branches with a thirty-minute exposure, whereas with a one-hour exposure we were able to accomplish the same results by using a 1½-ounce dosage rate. This demonstrates that decidedly better results can be secured by leaving the tents on the trees one hour than is possible with thirty minutes gassing. Whether more favorable results can be accomplished in one and a half hours than in one hour can not be determined from these experiments, since the trees in experiment No. 3 were of a smaller size than those in experiments Nos. 1 and 2. This matter of the large or small size of the trees is a vital factor in affecting the results obtainable.

Judging solely from the data at hand, we are forced to the conclusion that one hour is the more satisfactory length of exposure. Further experiments may show that a longer exposure will produce better results, or even that a forty-five or fifty-minute exposure will produce results as satisfactory as are obtainable in one hour. We hope in the near future to be able to fully settle this question. Until this is done, however, it would appear advisable to adhere to the one-hour length of exposure which is now generally employed in southern California. The considerations upon which this conclusion is based are as follows:

Experiments have demonstrated conclusively that with an exposure of one hour we can obtain decidedly better results than with an exposure of thirty minutes. If we give the tree an exposure of thirty minutes, it will require a considerably larger amount of cyanid to accomplish the same result. It requires approximately one hour for an outfit to go through the complete operation of preparing the chemicals and shifting 30 to 33 tents—the number usually employed. The tent pullers, by the time the end of the row is reached, are usually as much as five minutes, sometimes more, ahead of the one who handles the chemicals. As a result, the last trees of a row are exposed to the gas about fifty-five minutes, or a little less, under the present system, whereas an hour is supposed to be the length of exposure throughout. Thus if fifty minutes is found to give as satisfactory results as an hour, it would be poor policy to reduce the general exposure to this basis, inasmuch as with a general exposure of one hour some trees are already receiving but little more than fifty minutes.

As a rule, very little gas remains under the tent at the expiration of one hour. The amount is usually so small that the mortality among the scale-insects could be but slightly increased by greatly lengthening the exposure. Various authorities have recommended two hours or more as the duration of exposure, and it is possible that these long exposures would produce slightly better results than an exposure of one hour.

From the standpoint of the fruit grower, who requires the best results at the least possible expense, the item of time is highly important. The question which must be considered is whether it is more advantageous to sacrifice time or cyanid. No doubt it is cheaper to sacrifice time up to a certain point, but beyond this it is cheaper to sacrifice cyanid. As previously stated, the mortality among scale-insects, when a two-hour exposure is employed, might be slightly greater than at one hour. Before advising a two-hour exposure, however, we must determine whether or not it would be more economical to employ an exposure of one hour and use sufficient cyanid to accomplish the same results secured by the longer time. Fumigators are usually paid by the hour. Where tents are left on the trees two hours, with the same number of tents the cost for labor is exactly twice that for one hour. From 4 to 6 men, at an average wage of 35 cents per hour, are used on an outfit (infrequently 3), making the hourly cost for labor from $1.40 to $2.10. This would purchase from 5 to 7 pounds of cyanid.[a] Under these circumstances, if we can obtain as good results in an hour by using 5 to 7 pounds more of cyanid—or a smaller amount, according to the number of men in the outfit—it would be more economical in the end to use the additional cyanid and expose for the shorter time. The writer's own field experience leads him to believe that as good results can be accomplished in one hour as in two hours by using an amount of cyanid costing far less than would the extra hour's labor.

It will be seen that the question before the fumigator is not simply one of using that length of exposure which will produce the best results, but that which will at the same time be most economical. From field experience and other considerations the writer is led to believe that this will be between fifty minutes and one and one-half hours.

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[a] Cyanid is here considered as including acid, both costing about 28 cents per pound.

ERADICATION OF THE PURPLE SCALE.

The foregoing experiments have shown that the purple scale can be eradicated from citrus trees, provided a dosage of sufficient strength be used with a sufficient exposure. This dosage strength is much greater than that at present used in fumigation.

If the purple scale can be everywhere eradicated by using a dosage of definite strength (which we hope to determine in due time), the question will immediately arise in the orchardist's mind whether it will be profitable to use this heavier dosage provided it can be employed without injury to the tree and fruit. In deciding this question several practical considerations must be taken into account. The trees, as will be shown later, are in a condition to stand this heavy dosage without injury during but a limited portion of the year. It would be impossible for the number of outfits at present in existence to fumigate the infested area within this limit of time. Moreover, unless compelled to do so the orchardists in any locality would not all use this dosage. Whether it would be advisable for a grower to incur the additional expense for this heavier dosage in his orchard when the infested orchards on all sides of him are fumigated with lighter dosages, if at all, must be determined by large-scale tests. The foregoing are some of the difficulties in respect to the use of this heavy dosage.

DIFFICULTY OF DESTROYING THE SCALE ON THE FRUIT.

There is one more important point which must be considered in connection with fumigation for the purple scale. It will be seen in an examination of the data from the foregoing experiments that an orchardist, fumigating trees containing purple scale in its different stages on the fruit as well as on the leaves and branches, would, except with the heaviest dosages, leave on the fruit healthy eggs soon to hatch and infest other parts of the trees. It would be impractical under most circumstances to use a dosage heavy enough to destroy the eggs on the fruit. The cost of the extra cyanid required, above that necessary for the destruction of the eggs on the leaves and branches, would be more than the scaly fruit is worth. Therefore in fumigating for eradication it is advisable to remove the infested fruit, and it is advisable to remove the old scaly fruit in any fumigation. At picking, fruit badly infested with scale is usually left on the tree, and frequently from one to a half dozen or more old, scale-infested oranges per tree remain throughout an orchard. Even after a good fumigation one of these old fruits might carry more healthy purple-scale eggs than all the rest of the tree, and on the hatching of these eggs the insects will spread to other parts of the tree. The danger from old scaly fruit is evident and all such should be removed from the trees before fumigating an orchard.

GENERAL CONSIDERATIONS.

LEAKAGE OF GAS DURING OPERATIONS.

One of the most important questions relating to the proper dosage in fumigation is that of the leakage of gas through the tent; in fact, the dosage depends directly upon the leakage. To measure with accuracy the amount of gas which escapes through tenting fabrics of various grades during a given length of time, or the rapidity with which the gas within the tent is diluted under different conditions, is a difficult problem. In this work, as far as we have progressed, no attempt has been made to measure directly with instruments the rapidity with which the gas is diluted, but rather to measure it indirectly and roughly through determining the effect on insects by using different durations of exposure. The easiest and most practical method of determining the influence of leakage is by fumigating trees of the same size, in which all factors affecting the results are identical with the exception of the length of exposure.

There is, however, one consideration of value relative to the leakage of gas, which it is quite necessary to understand in successfully fumigating an orchard containing trees of a wide range of size. In geometrical figures which approximate in shape a citrus tree, the volume decreases at a more rapid rate than does the surface area. In order to bring out the relation of this fact to orchard fumigation, the following table has been prepared:

TABLE VII.—*Leakage of gas from tents covering trees of different dimensions.*

Dimensions of tree. Around.	Dimensions of tree. Over.	Contents or volume of tented tree.	Exposed surface of tent.	Leakage surface as per cent of volume.[a]
Feet.	*Feet.*	*Cubic feet.*	*Square feet.*	*Per cent.*
20	12	99	85	86
30	19	364	205	56
40	28	1,040	420	40
50	36	2,147	675	31
60	44	3,819	995	26
70	54	6,605	1,445	22

[a] The comparison here and in the discussion which follows is between square feet of surface and cubic feet of volume.

Taking the first tree, 20 feet around by 12 feet over, representing a volume of 99 cubic feet and an exposed surface area of 85 square feet, the ratio of leakage surface to volume is 86:100. For each cubic foot of volume within that 20 by 12 tree there is 0.86 square foot of leakage surface in the tent. The tree 40 by 28 feet has 0.4 square foot of leakage surface for each cubic foot in the tent, while a tree 70 by 54 has but 0.22 square foot of leakage surface to each cubic foot within. Suppose that these tented trees were charged with gas and that all the gas were to escape through the tent. In the first tree, 20 by 12 feet, there would be 0.86 of a square foot of tent surface for each cubic foot of gas to escape through; whereas in the last tree, 70 by 54, there would be only 0.22 of a square foot of tent surface for each cubic foot to escape through. This would mean that there would be about four times as great an opportunity for leakage, or that the leakage would be approximately four times as rapid in the smaller tent as in the larger one.

There can be little doubt that the leakage of gas in tents covering different-sized trees is nearly in accordance with these figures. Hence it can be readily seen that, in order to secure uniformity of results, this leakage must be taken into consideration, and small trees must receive more cyanid per 100 cubic feet than do the larger trees.

The correctness of the foregoing deduction has been frequently demonstrated in the field. In using on a smaller tree a certain dosage strength with which on large trees we were able to secure splendid results against the purple scale, we were always much less successful. In other words, if we used 1 ounce of cyanid per 100 cubic feet on the 70 by 54 foot tree, we would get far better results than had we used the same dosage rate on the 20 by 12 foot tree. A very forcible exemplification of this condition has been given in experiment No. 3, in fumigating for the purple scale. In this particular experiment much less satisfactory results were secured on the small trees when using a one and one-half hour exposure than on the large trees of experiment No. 2, with a one-hour exposure.

TIME OF THE YEAR FOR FUMIGATION.

Although fumigation is carried on in California at all times of the year, there are certain periods in which the operations are more general. There are two main factors to be taken into consideration in fumigating, i. e., the species of scale-insect and the condition of the tree. As to the latter, it may be said that at certain periods of the year trees are in such a tender condition that they can not withstand a heavy dosage without injury, especially to the fruit.

The bulk of fumigation in California at the present time is carried on between the latter part of August and December. Probably the principal reason for fumigating during this period is that at this time the black scale is most successfully reached. The eggs of the black scale, and the insects themselves when full grown or nearly so (commonly spoken of as in the "rubber" stage), require very heavy dosages. On the other hand, the young of the black scale, or those which have not reached the so-called "rubber" stage, can be destroyed with a moderate dosage. Although the life history of the black scale has never been thoroughly worked out for the region with which we have to do, it is generally understood that the majority of the insects of the large and more regular brood are hatched and in their least resistant stage during September and October. In some favorable seasons the eggs are almost all hatched in August. Moderately light fumigation dosage may be used against the black scale during this period with success.

The black scale occurs in practically every citrus-growing locality of southern California, while the purple, red, and yellow scales, the other principal citrus pests, are more localized. A heavier dosage is used for the latter insects than for the black scale. Where the other species occur in orchards infested with the black scale, it is a common practice to fumigate during the regular black-scale period, using the heavier dosage. The majority of these scale insects can thus be caught at one time. When fumigating for the purple scale alone, operations may be commenced as early in the season as the trees are in a condition to withstand the heavy dosage without injury, although probably it would be preferable to fumigate a little later in the fall. The purple scale is to be found in the egg stage throughout the year. There is a period in the fall and one in the early spring, however, during which the smallest proportion of eggs is to be found. With dosages lower than those of eradication, the best work can be accomplished at these times.

The red and yellow scales are viviparous and can be successfully destroyed throughout the year.

In fumigating for any of the scale-insects there is one point worthy of consideration. Aside from trying to save the tree from destruction or from having its vitality impaired by the attack of scale pests, the orchardist fumigates principally in order to have his fruit come into the packing house as clean as possible. It would be well, therefore, to fumigate as nearly as possible to the time which would insure him the cleanest fruit. Although lemons are gathered throughout the entire year, the bulk of the orange crop is taken during the first six months. Thus fumigation during the fall and early winter would be sure to place the cleanest fruit in the packing house. If carried on in the late spring or early summer, such insects as remain undestroyed would have the opportunity to breed through a period of several months and infest much fruit.

FUMIGATION DURING THE BLOSSOMING PERIOD.

The statements by experts on fumigation as to the amount of injury resulting from work while the trees are in blossom are very conflicting. Some fumigators hold that a very light dosage will destroy the tender blossoms, while others believe that the blossoms will stand a heavy dosage. In order to decide this point much experimentation was carried on and many observations made throughout the blossoming period of 1908. Some of the results secured are given in the following paragraphs.

Experiment No. 1.—On February 28 and 29 about one-third of an acre of mixed Valencia and Navel orange trees was fumigated at Upland, Cal., using dosage rates of 1 ounce and 1½ ounces per 100 cubic feet. The trees were about 12 feet in height. At this time the blossoms were just appearing on the trees, none of them being far enough advanced to open. The general conditions of the blossoming may be understood by an examination of figure 14. This

FIG. 14.—Orange blossoms at an early stage of development. (Original.)

may be considered the tenderest stage of blossoming. An examination of these trees two weeks later showed that no apparent injury had resulted and that the trees at this time contained as heavy a set of blossoms as the surrounding unfumigated trees.

Experiment No. 2.—On March 30 fully 1 acre of Navel and Valencia orange trees about 10 feet high were fumigated at Orange, Cal., using dosage rates of 1, 1½, and 2 ounces per 100 cubic feet. The condition of blossoming at the time of fumigation ranged from no open blossoms on some trees to full blossoms on others. An examination of these trees at a later date showed that with the 1 and 1½ dosage rates no apparent injury had been done. The 2-ounce rate had caused a considerable percentage of the blossoms to drop, yet not enough to lessen the coming crop of fruit to any great extent, if at all.

Experiment No. 3.—During the months of April and May, 25 acres of Valencia and Navel oranges at Glendale, Cal., were fumigated by an expert under the direction of the Los Angeles horticultural commission. While this fumigation was in progress, trees could be found in all stages of blossoming, from those with blossoms just appearing to those in full bloom. The dosage rate used was estimated to be from three-fourths to 1 ounce per 100 cubic feet. Of course this rate varied with different trees, since the dosage was estimated after the usual guesswork method. Several examinations of the orchard were made. Although blossoms were injured on some of the trees, the number was so small as in no way to lessen the future crop of fruit.

Other instances might be mentioned, but the results correspond practically with those in the three experiments already described. Trees in which there were blossom-shoots and tender leaf-shoots side by side would have the leaf-shoots burned back while the blossoms remained uninjured. Also numbers of cases could be found where the tender leaves on the blossom-shoots were burned while the blossoms themselves remained uninjured. This, as well as the heavy dosage which the blossoms will stand without injury, would lead us to conclude that the blossoms will stand a heavier dosage than the tender leaves and leaf-shoots. These experiments also show that fumigation can be safely conducted during the blossoming season, using such dosages as are at present generally employed by fumigators, or are advised in dosage schedule 1 (p. 65).

FUMIGATION WHILE THE FRUIT IS OF SMALL SIZE.

Experiments and observations to determine the effect of fumigation on fruits of various sizes, and more especially on small fruits, were made during the season of 1908. Conflicting opinions on this subject are prevalent.

Experiment No. 1.—On June 16 two Valencia orange trees about 8 feet in height, in a healthy condition, and containing young fruit from three-eighths to one-half inch in diameter, were fumigated at the 2-ounce dosage rate. Fully 25 per cent of the fruits on these trees were pitted or burned.

Experiment No. 2.—On June 24 a somewhat unhealthy Navel orange tree about 12 feet in height, with the fruits about one-half inch in diameter, was dosed at the rate of $1\frac{1}{2}$ ounces. Fully 50 per cent of the fruits were pitted. Two healthy Valencia orange trees about 10 feet in height, with fruits practically the same size as in the case of the Navel tree, received a dosage at the rate of 2 ounces. About 40 per cent of the fruits were burned.

Experiment No. 3.—On July 11 and 13, four Valencia orange trees were fumigated, using a 1¼-ounce dosage rate, 4 trees receiving a 1½-ounce dosage, 8 trees a 1¾-ounce dosage, and 4 trees a 2-ounce dosage. These trees were in a perfectly normal condition, about 7 to 8 feet high, and contained young fruits fully three-fourths of an inch in diameter. With the 1¼-ounce dosage rate no fruit was burned; with the 1½-ounce rate an occasional orange was slightly burned; with the 1¾-ounce rate a very small percentage was burned, while with the 2-ounce rate a considerable percentage was injured. This demonstrates that a 2-ounce dosage rate could not be safely used on trees of this size.

Experiment No. 4.—During the middle of July a large number of orange trees of all sizes were fumigated at Santa Fe Springs, Cal., using various dosage rates. The trees fumigated were of several varieties, in a healthy condition, and all well filled with fruits about the size of an English walnut and slightly larger. It was found from this experiment that a dosage rate of 1 ounce to 100 cubic feet could at this time be used without injury on orange trees 15 to 16 feet high. Only an occasional orange was burned by 1¼ ounces. Smaller trees proved able to stand a heavier dosage than larger ones without appreciable injury.

On the basis of information obtained from experiment No. 4, dosage schedule 1 (p. 65) was prepared. This schedule was put into use during the latter part of July and has been in use, up to the time of writing, by two outfits, at Whittier, Cal. Although no noticeable injury to the fruit has resulted from the use of this dosage, the general effect on the tree has indicated that a heavier dosage could not have been used with safety.

A further example of the tender nature of small fruits was shown in some work done by an excellent fumigator at Downey, Cal., during the latter part of May. The fruits were for the most part three-eighths of an inch or less in size, while the trees were thoroughly infested with scale and in a generally unhealthy condition. So far as could be determined, a dosage rate of approximately three-fourths to 1 ounce was used. The larger percentage of the fruits on these trees was burned. Other instances of like fumigation, where the fruits were one-fourth inch or less in diameter, have been seen. The fruit at this period is very tender. Doubtless it is the most critical period of any during which fumigation is conducted.

From the foregoing, it is evident that heavy dosage can not be used while the fruits are small without more or less injury, and that the most critical period during which fumigation may be conducted is between the time when the fruits are set and the time when they attain the size of a walnut.

SIMPLE METHOD OF REMOVING ACID FROM DRUMS AND CARBOYS.

The writer has at times been obliged to employ rather awkward methods in drawing acid from drums and carboys, and other fumigators have doubtless met with the same trouble under like circumstances. Brief mention will be made of some of the best methods which have been brought to notice to obviate this difficulty.

From drums.—The best method of taking acid from drums known to the writer is that at present in use in San Bernardino County and is shown in figure 15. The apparatus consists of a lead-lined tank large enough to hold a drum of acid and having an outlet through

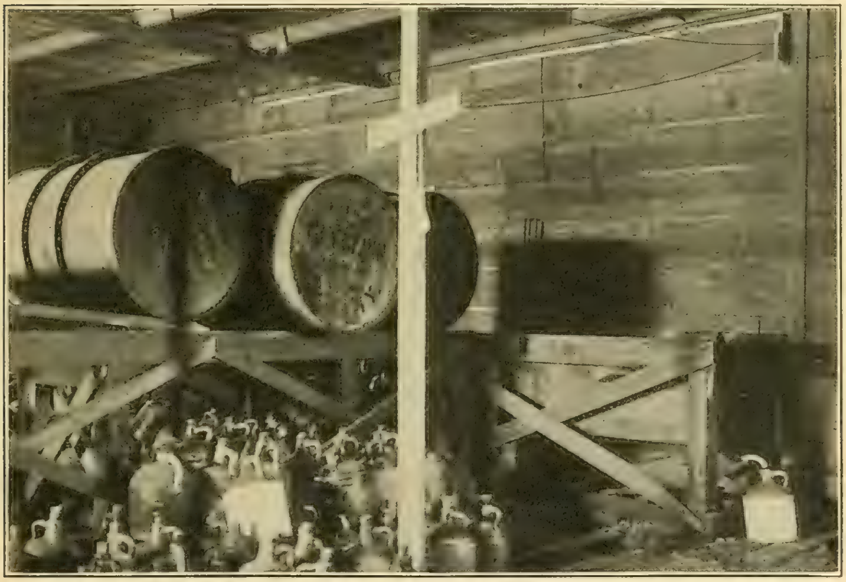

FIG. 15.—Lead-lined tank used in San Bernardino County for removing sulphuric acid from drums and for filling jugs. (Original.)

which the acid may be drawn into carboys, jugs, or whatever vessels are preferred for field use. A drum of acid is rolled from the wagon upon two parallel beams and along these beams onto a small turntable at the tank. This turntable is then revolved through a quarter circle, permitting the drum to be rolled out over the lead-lined tank, into which the acid is then allowed to flow. The acid may be drawn as previously mentioned. The outlet is made of lead tubing, fitted at the tank end with a lead valve by which the flow is regulated.

Another very satisfactory way of drawing acid from drums came to the writer's attention in examining some operations at Glendale, Cal. It consists in the use of a short iron pipe threaded at one end so as to fit the opening in the drum. The one difficulty with this device is that the flow of acid is uneven and spouting. To offset this, Mr. William Wood, of Whittier, Cal., has contrived a small copper tube for attachment to the pipe, one end of the tube being exposed to the open air, the other end extending up above the level of the acid within the drum, thus allowing an uninterrupted flow of air into the latter. This apparatus is illustrated in figure 16.

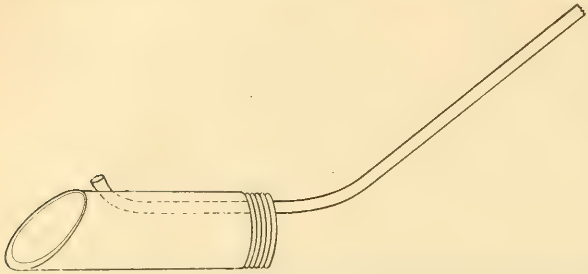

FIG. 16.—An improved pipe for removing acid from drums. (Original.)

A third method in use is to transfer the drums from the wagon to a platform 2 or 3 feet high. The acid may then be removed very easily by means of a piece of rubber hose employed as a siphon (fig. 17).

FIG. 17.—Siphoning acid from drums by means of a rubber hose. (Original.)

From carboys.—Two common methods used for removing acid from carboys in the field are shown in figures 18 and 19. In the first method a small amount of dirt is placed against one side of the carboy, furnishing a sort of rest when the latter is tipped to remove the acid. It is well to scoop out a small pit below this ridge of dirt, into which the vessel receiving the acid may be lowered when the acid is so largely removed that it is necessary to turn the carboy far on its side in order that all may be withdrawn.

In figure 19 the handles on the carboy are substitutes for the heap of dirt and the pit. They are also of service in carrying the carboy.

THE PROTECTION OF CYANID.

Many fumigators do not attempt to cover their cases of cyanid, but leave them open during the day. This not only constitutes a source of danger to various animals, but also during the wet season allows water to reach the cyanid. Figure 20 shows a simple lid covered with zinc which is suitable for placing on a cyanid case to protect its contents.

FIG. 18.—Carboy resting against a heap of dirt to facilitate pouring the acid. (Original.)

HYDROCYANIC-ACID GAS IN DRUMS.

Some discussion has arisen during the past year relative to the possibility of introducing hydrocyanic-acid gas into drums under pressure, and using it directly from the drums, thus doing away with all generation in the field. The use of this gas under pressure from drums is impossible at the present time for two reasons: (1) No drums are made which will hold hydrocyanic-acid gas without corroding; (2) we know of no instrument which will measure gas accurately under varying degrees of pressure, such as would exist in removing a gas under pressure from drums.

THE MARKING OF TENTS.

Before new tents are marked they should have been in use for a short time, so that they will be thoroughly shrunken. This shrinking may be accomplished, in regions of heavy dews or fogs, by simply leaving the tents exposed in the open for a few days. Dipping in water or sprinkling by means of a hose and then allowing the tent to dry in the sunshine will answer the same purpose if repeated several times. The shrinkage of a new 45-foot tent will sometimes be as much as 3 feet. Tents marked before being shrunk will have erroneous graduations.

FIG. 19.—Carboy with handles attached to facilitate pouring the acid and carrying the carboy. (Original.)

The most satisfactory material to use in marking tents is diluted printer's ink. This ink is commonly used in California in marking walnut bags. If the ink is too thick to mark freely, it may be diluted with kerosene. Printer's ink does not cause the cloth to deteriorate. A mixture of lampblack and turpentine may also be used with entire safety. The latter, however, will sometimes rub off to a slight extent.

A DEVICE FOR COVERING FUMIGATION GENERATORS.

During the course of this investigation much effort has been directed toward perfecting a device for attachment to the top of the commonly used open-style fumigation generator that will serve to interrupt the direct rise of the hydrocyanic-acid gas. The result of these efforts, in which the writer was greatly aided by Mr. Frederick Maskew, is shown in figure 21. The device itself consists of a copper cover of such size as to make it available for use with any of the regular-pattern generators now employed by the fumigators of southern California. It is stamped in a concave form from a sheet of copper, with corrugations to permit the escape of gas. The shape is such as to conform to the size of the opening of generators of different capacities and also to direct the course of the escaping gas downward and distribute it uniformly through the lower part of the tent. It is attached to the generator by hinges of stout copper wire secured by a key bolt passing through the handle. The cover is raised by a slight pressure of the thumb on a projecting piece which is curved in such a manner that the cover will remain in an upright position when so required. When the generator is emptied of its contents, the cover swings clear by its own weight. A glance at the illustration will satisfy the practical fumigator that it is adapted to all the requirements of rapid work in the dark, while its use has demonstrated that it is simple, strong, and durable. It is very possible that if the copper cover were lined with a thin covering of lead its durability would be increased.

A common result of the use of heavy dosages of fine fragments of cyanid is the burning and ultimate dropping of many of the leaves directly above the generator in the pathway of the rapidly rising gas. This result is usually spoken of as the "chimney" effect. The generator cover eliminates this "chimney" burning.

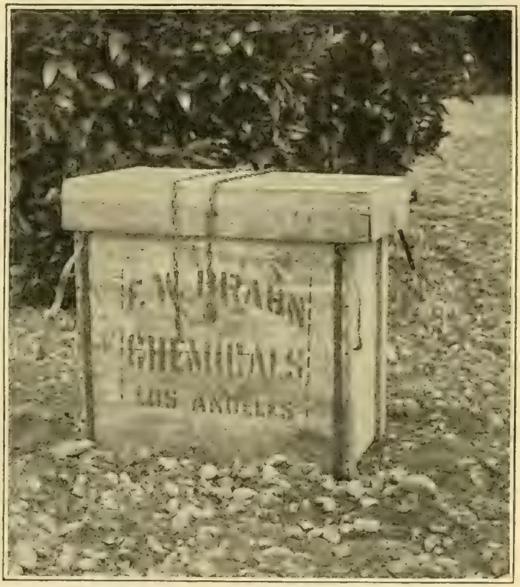

FIG. 20.—Zinc-covered top for protecting cyanid in the field. (Original.)

A second and highly important point is the effect of open generators on the tent. The outer part, or skirt, as it is sometimes called, of fumigating tents is constantly being perforated with small holes, even when used by the most careful of workers. We have noticed this effect to some extent in our own outfit, which we believe to be as carefully handled as any fumigation outfit could be. These holes are known to be acid burns. A few simple tests have demonstrated conclusively that many of these acid holes are due to acid carried along with the escaping gas and reaching that part of the tent nearest the generator. By placing large pieces of canvas in the path of gas escaping from open generators in which dosages similar to those often used in field work are employed, it was found that drops of acid reached the canvas as high as 5 feet from the ground. The writer has frequently seen generating vessels placed not more than 2 feet inside the tent. At such a distance one can readily see that drops of acid might reach the tent. The generator cover described above so deflects the gas, and incidentally such acid as is carried with it, that the drops are thrown to the ground, thus saving the tents. The decreased cost in mending of tents will doubtless pay for the cost of such a cover device several times over in a fumigating season.

A third advantage, which we have not as yet demonstrated but which we have reason to believe will develop, is a better distribution of gas through the tent. Heretofore the most difficult part of the tree in which to destroy insects is the lower part. This is also the part of the tree in which the purple scale is largely to be found. With the open generator the gas rises straight up in a narrow column for several feet (fig. 22, at left), being broken up and distributed through the top of the tree first. As the gas is lighter than air, it is not to be expected that it will quickly become uniformly distributed throughout the bottom of the tent, even if at any time it becomes as concentrated here as at the top. The greater burning effect and better killing effect in the top of the tree would tend to substantiate this assumption. Field observations in fumigating large trees show that the gas is of no great strength at the lower part of the tent for several minutes after the charge is set off. With this new cover the gas is broken up and distributed through the bottom of the tent first (fig. 22, at right). By the time it reaches the top it is pretty generally distributed throughout the tent. As the bottom of the tree is the first to receive the full benefit of the gas, a more complete killing of scale at the bottom of the tent may be expected than with an open generator.

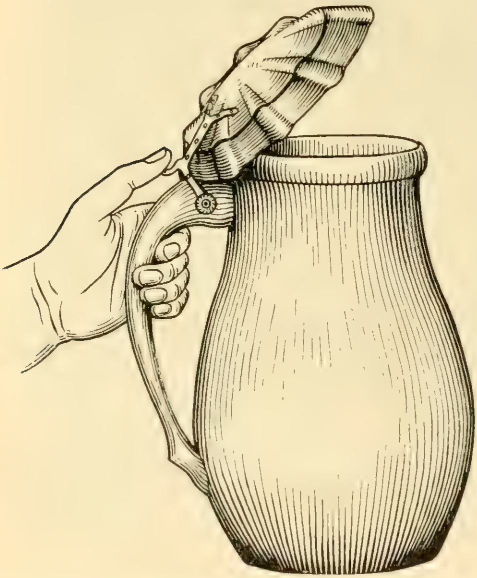

FIG. 21.—A cover device attached to a fumigation generator; corrugations in cover allow gas to escape. (Original.)

AN IMPROVED SYSTEM OF FUMIGATION.

During the month of July, 1908, a system of fumigation which has decided advantages over the old method was introduced into California field practice. In this system the tents are marked after the Morrill method, described on pages 27–30 (figs. 11 and 12). Only the three parallel lines are used, the cross line being unnecessary and to some extent a disadvantage in practical work. The marking on these lines gives us an easy means of determining the distance over the top of the tree. Our experience has shown that the distance around the tented tree can be measured very accurately by pacing. The one whose work, in a regular outfit, is to obtain the dimensions of the trees, should make several practice trials in advance of fumigation, so as to determine the exact length of his pace, and to regulate it, if necessary. In pacing the distance around a tree it is well to keep far enough from the edge of the tent—say from 6 inches to 1 foot distant—to prevent the body from coming into contact with it. The length of the pace should be regulated to 2½ or 3 feet when approximating the actual distance around the tented tree, preferably 3 feet, if the pacer can step that distance without much exertion. In reality the distance paced will be slightly greater than the actual circumference of the tent. From these two measurements (the distance around and the distance over), it is possible to approximate the cubic contents of the tree.

FIG. 22.—Difference in the direction taken by gas escaping from an open generator and from one covered with the corrugated lid. (Original.)

SUPPLY CART.

With this system some change is necessary in the character of the vehicle for carrying materials, inasmuch as the measuring of chemicals is conducted at the tree. A two-wheeled handcart of the same general description as that in use by the San Bernardino County outfits has been adopted. The handle of the cart and the arrangement of the lights have been improved upon; while the use of faucets in drawing off the acid and water is also an improvement. One of the carts equipped for use is shown in figure 23. As purchased the cart bed consists of a plain box fitted with a two-shaft handle. This handle is removed, and is replaced by a tongue having an enlarged link-shaped iron about a foot long, firmly attached at the end. This link-shaped handle is very convenient in field work. The scales for weighing the chemicals are placed on a platform above the center of the box. The cyanid is contained in a tin-lined box in the rear half of the cart, while the acid and water are placed in the front end. A 10-gallon keg firmly attached in a horizontal position to the bed of the cart is a very convenient receptacle for the water. A galva-

FIG. 23.—Cart used with the improved system of fumigation. (Original.)

nized-iron basin like that shown above the keg in figure 23, having an opening at the bottom fitting into the bung of the keg, makes a very satisfactory funnel for filling the keg. The acid may be held in an earthenware jar or a lead-lined tank, with cover firmly attached to prevent slopping.

By way of a cover for the earthenware jar we have used a lead-lined lid, which fits tightly within the top (fig. 24). At the center of this lid is an opening about 6 inches in diameter, around the circumference of which is attached a leaden tube which extends downward several inches and prevents the slopping of acid through the hole. A lead-lined cover fits into the top of this tube. This opening in the cover is for use in filling the jar.

Very few metals will withstand sulphuric acid without corroding. For this reason all the common types of faucets are practically worthless for drawing acid. There is no faucet on the market that is altogether satisfactory for this purpose, although at the present time a manufacturing firm on the Pacific coast is experimenting in the hope of perfecting the necessary article. We have met this difficulty in an entirely practical manner by attaching a three-quarter inch iron pipe to the lower side of the jar and regulating the flow of acid by means of a large pinchcock placed on a short piece of rubber tubing at the end of the pipe (fig. 24, 1, 4, and 5). The flow of acid is rapid and easy to control. Pure rubber is most satisfactory and a fresh piece should be substituted about every other night.

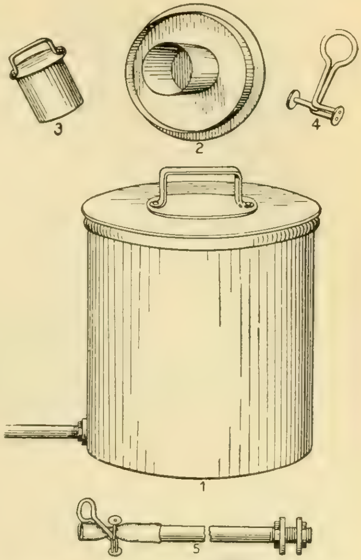

FIG. 24.—Earthenware acid jar with attachments for field use: *1*, Jar complete; *2*, inside view of lead-lined cover showing tube at center; *3*, copper top for opening in cover; *4*, pinchcock; *5*, method of attaching iron pipe to jar, and rubber tube on end of pipe with pinchcock attached.

The water is drawn from a faucet. In order that this may be drawn on the same side of the cart as the acid, a pipe of the character shown in figure 23 is required. The faucet should have an opening of about three-fourths inch to allow a heavy flow and should be of such a type that a half turn will give it a full opening.

As fumigation is usually conducted at night a torch is placed on the front of the cart to furnish a light by which to measure the acid and water; one on the elevated platform is convenient for the man measuring the cyanid.

This style of cart is entirely practicable for almost all fumigation work. The chemicals can be measured quickly and accurately without any slopping of acid or water. The work is also easier on the men in charge than under the old system. On ground which is so rough that a wheeled cart can not be drawn, a portable table may be used. Such a table as is shown in figure 25 can be easily utilized for such a purpose.

PROCEDURE.

Five men are required to operate this system to advantage. Two men pull the tents and kick in the edges around the bottom of the tree. One man takes the measurements of the tree and determines the dosage from a dosage schedule which he carries with him. After determining the dosage he should empty the generator to be used for that tree and have it in readiness by the time the cart arrives. *The* *generator should always be emptied with one and the same hand and with this hand he should never touch the tent;* otherwise acid burns

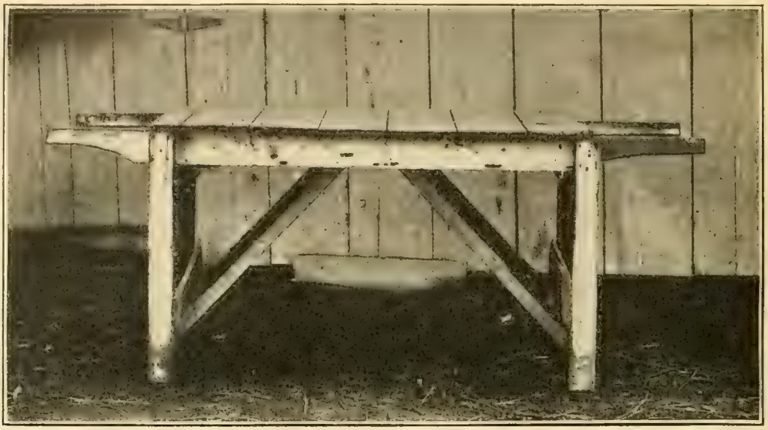

FIG. 25.—A table which can be used instead of a cart in fumigation over very rough ground. (Original.)

may result. The estimator should also be foreman of the outfit, as this is the most responsible position of all. Two men work at the cart. One measures the water and acid, the other weighs the cyanid. The latter holds up the edge of the tent while the acid man places the charge beneath the tree.

FIG. 26.—A row of tented trees, and cart at one end ready for dosing. (Original.)

In actual field practice the cart is first brought up to one end of the row which is to be fumigated (fig. 26). The estimator obtains his measurements and calls out the dosage. The two men then measure out the required amount of chemicals and dose the tree (fig. 27). While they are thus engaged the estimator has moved on to the next tree, determined the proper dosage, and holds the generator in readiness when the cart is brought up. He then calls out the dosage with which the tree is to be treated. This procedure continues in like manner until the entire row is fumigated.

Outfits employing this system have, on an average, been fumigating a complete set of 32 tents in from forty to forty-five minutes.

FIG. 27.—Dosing a tree. (Original.)

This would appear to demonstrate that the system is entirely practicable from the standpoint of time economy, as tents are usually required to be left on the tree one hour.

ADVANTAGES UNDER THIS SYSTEM.

First.—The element of guesswork in estimating dosage and the consequent waste of cyanid are eliminated, since the dosage is determined according to a uniform method in all cases. If a dosage of sufficient strength to destroy 90 per cent of the purple scale is used, practically 90 per cent of the purple scale is killed on every tree throughout that orchard—not 90 per cent on some trees and 50 per cent, more or less, on others, which has occurred at times under the old method. Or if a dosage strength just sufficient to eradicate the pest is employed, a like result will occur throughout the orchard and there will be no great waste of cyanid by reason of many trees receiving a larger dosage than was necessary.

Second.—An economy of cyanid results from the accurate measurement of the water. Three parts of water are always used, resulting in the maximum amount of available gas for practical work, as already explained (pp. 38–39). Under the old system the water is usually measured with an ungraduated dipper at the tree, and as the cyanid and acid have been previously measured out into small cans, which are in turn placed on a tray to be carried from tree to tree, the schedule is not carried along for consultation in estimating the water, but the required amount of water is guessed at from the amount of chemicals in the cans intended for that particular tree. Owing to the variation in the proportion of water which results in this way, the maximum amount of available gas is seldom produced by the reaction.

Third.—By the old method the cans on a tray sometimes become confused, in consequence of which some trees get the dosage measured out for others. This error is eliminated under the improved system, as the dosage for each tree is measured out just before that particular tree is fumigated.

Fourth.—The tent pullers seldom get more than one or two trees ahead of the cart. As a result, all trees receive the same length of exposure. Under the old system, when the tent pullers got far ahead of the cart at the end of a row, these trees received a much shorter exposure than the first trees.

DOSAGE SCHEDULE.

Having obtained the dimensions of the tented tree, the next step is to determine the dosage. It has been previously stated that the cubic contents can be calculated from these two dimensions. This might be done in the field and the trees then dosed in proportion to the contents. The time required for the calculation of the dosage, however, even after determining the cubic contents of the tree, would not only prevent rapid field work and allow an opportunity for error, but would cause a lack of uniformity in dosage, from the consideration of the cubic contents alone, as will be explained later. This difficulty has been obviated by preparing a dosage schedule from which the required dosage may be learned without any figuring as soon as the measurements of the tree are known.

The orchardists in the citrus section about Whittier, Cal., desired to commence fumigating for the purple scale during the latter part of July. The question immediately arose as to what dosage could be used at that time of the year without injuring the young fruit. As stated under experiment No. 4 (p. 52), while the fruit is small a dosage of 1 ounce to 100 cubic feet could be used on trees from about 10 to 15 feet in height without injury to the fruit, whereas smaller trees would stand a heavier dosage. As this was the limit of dosage which could be used at that time of the year without injury to the young fruit, the writer prepared a schedule based upon this data.

According to this schedule, trees 41 feet in circumference by 28 feet over the top, from ground to ground, receive 1 ounce of cyanid for each 100 cubic feet of inclosed space. This proportion is increased on smaller trees, while on trees which are larger it is decreased to offset the proportionately smaller leakage (pp. 43–44, 47–48). In preparing the schedule the writer began with a tree 41 feet in circumference by 28 feet over the top. The cubic contents of this tree were determined

	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	
10	1	1	1	1½	1½																												10
12	1½	1½	1½	1½	2	2	2½																										12
14	1½	2	2	2½	2½	2½	3	3	3½	4	4½	5																					14
16	2	2½	2½	3	3	3	3½	3½	4	4½	5	5½	6	7																			16
18			3	3	3½	3½	4	4½	4½	5½	5½	6	7	7½	8																		18
			20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	
20				3	4	4½	5	5½	5½	6	6½	7	7	8	8½	9	9½																20
22					4½	5	5½	6	6½	7	7½	7½	8	8½	8½	9½	10	10½															22
24						5½	6½	7	7½	8	8½	9½	9½	9½	10	10½	11	11½	12														24
26							7	8	8½	9	9½	10	10½	10½	11	11	11½	12	13	14	14½	15											26
28								8½	9½	10	10½	11	11½	11½	12½	12½	13	13½	14	14½	15½	16											28
								30	32	34	36	38	40	42	44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	
30									10	11	11½	12	12½	13	13½	14	14½	14½	15	15½	16½	17½	18	19	20	20½	21½						30
32											12	12½	13	14	15	15½	16	16½	17	17½	18	18½	19	19½	20½	21½	22½						32
34												13	14	15	16	17	17½	18	18½	19	19½	20	20½	21	21½	22½	23						34
36												14	15	16	17	17½	18	19½	20	20½	21½	21½	22	22½	23	23½	25½						36
38													16	16½	17½	18½	19	20½	21	21½	22	23	23½	24	24½	25	25½						38
													40	42	44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	
40														17	18	19	20	21	22	22½	23	24	24½	25	25½	26	26½	27	27½	28			40
41														18	19	20	21	22	22½	23½	24	24½	25	25½	26	26½	27	27½	28	28½	29		41
42															20	20½	22	22½	23	24½	25	25½	26	26½	27	27½	28	28½	29	29	30	30½	42
43																21½	22½	23	23½	25	25½	26	26½	27	27½	28	28½	29	29½	30	30½	31	43
44																	23	23½	24	25	26	26½	27	27½	28	28½	29	29½	30	31	31½	32	44
																		50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	
45																		24	25	26	26½	27	27½	28	29	29½	30	30½	31	31½	32	33	45
46																		24½	25½	26½	27½	27½	28	28½	29½	30	30½	31	31½	32½	33	34	46
47																		25	26	27	27½	28	28½	29	30	30½	31½	32	32½	33	34	35	47
48																		25½	26½	27½	28	28½	29	29½	30½	31	32	32½	33	34	35	36	48
49																		26½	27	28	28½	29	29½	30	31	31½	32½	33	34	35	36	37	49
																		50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	
50																							30	31	31½	32½	33	33½	35	36	37	38	50
51																							31	31½	32	33	33½	34	36	37	38	39	51
52																							31½	32	33	33½	34	35	37	38	39	41	52
53																							32	32½	33½	34	35	36	38	39	40	41	53
54																							32½	33	34	35	36	37	39	40	41	42	54
																							60	62	64	66	68	70	72	74	76	78	
55																							33	34	35	36	37	37½	40	41	42	43	55
56																							34	35	36	37	37½	38	40½	42	43	44	56
57																							34½	35½	36½	37½	38½	39	41	42½	43½	45	57
58																							35	36	37	38	39	40	42	43	44	46	58
59																							36	36½	38	39	40	40½	42½	43½	45	47	59

FIG. 28.—Dosage schedule No. 1. (Original.)

and a dosage calculated which would give it 1 ounce to each 100 cubic feet. Trees of other dimensions, both larger and smaller, were then considered and their contents determined. In working out the dosage for these trees not only were the cubic contents taken into consideration, but also the rate of leakage as compared with that of the tree 41 by 28 feet. Trees which were smaller than this first tree would have a greater proportionate leakage rate, while the larger ones would have less. In securing the dosage for various trees, those smaller than 41 by 28 feet were given sufficient cyanid in excess of 1 ounce per 100 cubic feet to offset the increased leakage, while the dosages for larger trees were decreased proportionately below 1 ounce. This allowance for leakage so modified the schedule that trees 24 by 16 feet received as high as 1½ ounces per 100 cubic feet, while trees 60 by 44 feet received only about three-fourths of an ounce to the same space. The results of the use of such a schedule in practical fumigation should be that the smaller and the larger trees receive a dosage of uniform killing power against the scale.

After computing the dosages for trees of such sizes as would include all that could be covered with a tent 60 feet in diameter, a chart was prepared (fig. 28) and the dosages incorporated therein.

How to use the chart.—The top line of numbers, commencing at 16 and continuing through 18, 20, 22, etc., up to 78, represents the distance, in feet, around the bottom of the tent. The outer vertical columns of larger numbers, on either side, commencing at 10 and increasing regularly to 59, represent the distance, in feet, over the top of the tent. The dosage of a tree of known dimensions is found in that square where the vertical column headed by the distance around the tree intersects the horizontal line of figures corresponding to the distance over. For instance, we have a tree 40 feet around by 28 feet over. Looking in the top line of numbers we find 40 next after the third heavy vertical line. The dosages computed for trees 40 feet around are to be found in the vertical column headed by this number, which commences with 6 and ends with 16. Then we glance down the vertical column of large figures at either margin until we come to 28. All dosages computed for trees 28 feet over are found in this horizontal line of figures, which commences with 8½ and ends at 16. The dosage for a tree 40 by 28 feet is found at the intersection of this line with the vertical column headed with 40, that number being 11½, the required dosage of cyanid in ounces. Before the numbers 20, 30, 40, 45, 50, and 55, in the lines at the right and left margins are to be found blank spaces, and in the horizontal lines corresponding to these the numbers at the top of the chart are repeated in that part of the chart containing dosage figures. These numbers, repeated in this manner, make it easier for the eye to locate with certainty the dosage figures sought. In the chart used by the writer, the figures representing distances around and over are printed in red. The lines bounding these columns of figures are also red. All the rest of the lines and figures are black.

This schedule has been called "dosage schedule No. 1," by reason of the fact that 1 ounce to 100 cubic feet of inclosed space was taken as a basis in preparing it, though, as a matter of fact, only a small number of the trees in an orchard receive exactly 1 ounce to 100 cubic feet.

It is not maintained that this table is accurate to the minutest part of an ounce for every dosage, but the writer believes that such variations as may be found to exist are so small that in practical work in the field the results in killing scale-insects, from the use of any part of the table, will be found as satisfactory as from the use of any other part. Moderately heavy dosages almost invariably burn the tender shoots of a tree to a greater or less extent. Under this schedule practice has demonstrated that the tender growth is uniformly burned back in all cases, whether large trees or small ones are fumigated.

As previously stated in this discussion, dosage schedule No. 1 was prepared for use against the purple scale at Whittier, Cal., during the latter part of July when the fruits in some orchards were about the size of a walnut. The dosage employed was as great as the fruit would permit at that season without injury. This does not indicate that a larger dosage can not be safely used at other seasons of the year, if desired. The writer has at times employed a dosage of double the strength without visible injury to the trees. This was accomplished, however, under more favorable conditions, during the fall and winter months, when the fruit was well grown. It is not deemed advisable to use a dosage against the purple scale of less strength than that of schedule No. 1. If complete eradication is desired, a much heavier dosage must necessarily be employed.

The dosage in schedule No. 1 is equivalent to what is known among many fumigators as the "double dosage." It may be a little stronger than the double dosage of some, rather than weaker. "Double dosage" is usually intended to signify a dosage twice the strength required to destroy the black scale in its earlier stages.

Since this schedule is one of uniformity, it readily permits of manipulation. If a heavier dosage should be desired, such may be obtained by increasing each individual number or dosage in the same ratio; if a lighter dosage, by proportionately decreasing each. The schedule resulting from such increase or decrease will also be one of the same general uniformity as the first. The writer has prepared schedules which are $\frac{1}{2}$, $\frac{3}{4}$, $1\frac{1}{4}$, $1\frac{1}{3}$, and $1\frac{1}{2}$ times the dosage indicated in schedule No. 1.

THE IMPROVED SYSTEM IN USE.

Two outfits of the Whittier (Cal.) Citrus Association commenced the use of this improved system of fumigation, with dosage schedule No. 1, during the latter part of July, 1908. The apparent uniformity of work, indicated by the evenness with which the tender growth was burned back on all trees, immediately attracted the attention of citrus growers who saw the fumigated orchards. Their universal approval of the method is shown by the fact that not a single unfavorable comment was brought to the writer's attention throughout the entire fumigation work. The reception of an improved method with such unanimous favor by a community of California citrus growers demonstrates its value and economic importance.

Since the first outfits were placed in operation at Whittier, others have adopted the improved system of dosage, and at the time of writing this fully a dozen similar outfits in various parts of Los Angeles and Orange counties, Cal., are using the new method in preference to the old. That such a large number of practical citrus growers in widely separated localities, who have been employing a system of fumigation for many years, should accept an innovation within two months, strongly indicates its superiority.

FUMIGATION SIMPLIFIED.

In the past many persons have been prone to look upon fumigation as a process that is complex and more or less mysterious. In some cases fumigators of years' experience have encouraged this widely prevailing opinion, so that they might themselves be looked upon as experts in a practice difficult to understand and only capable of being successfully performed by men of long experience and special qualifications. This is, of course, erroneous. The improved system outlined in these pages shows how simple the practice of fumigation may be made. Careful men who have never before heard of fumigation can begin the practice of this system and are competent, after instruction for a short time, to secure as good results as might be expected from the most expert fumigator in California. This system reduces fumigation to a matter of simple mechanical operation, entirely intelligible to the average man, and one wherein the operator, to obtain the best results, is required merely to proceed according to the formulas and directions given.

This system makes it possible for the orchardists to possess outfits of their own—either individually or through joint ownership on the part of neighboring fruit growers—and to do the work with their own employees.

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