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ATTRACTANTS FOR THE JAPANESE BEETLE
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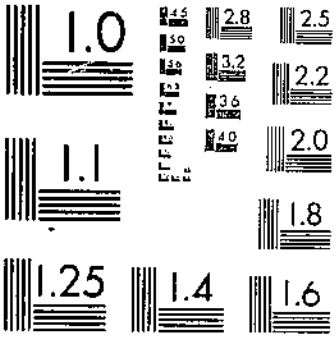

MICROCOPY RESOLUTION TEST CHART
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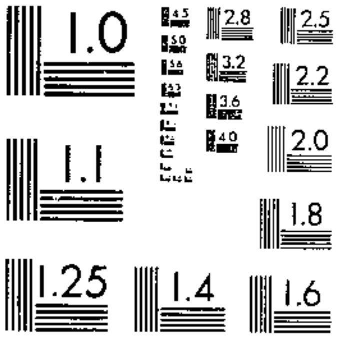

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ATTRACTANTS FOR THE JAPANESE BEETLE

Technical Bulletin No. 1399

Agricultural Research Service
UNITED STATES DEPARTMENT OF AGRICULTURE

Washington, D.C. Issued February 1969

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402–Price 45 cents

Contents

ATTRACTANTS FOR THE JAPANESE BEETLE

By Walter E. Fleming, *collaborator, Entomology Research Division, Agricultural Research Service*

There are three fields of investigation in the search for an odoriferous substance that can be used as a lure in traps and also will concentrate Japanese beetles on selected plants, where they can be killed by insecticides. They are the odoriferous constituents of plants preferred by the beetle and associated chemicals, fermentation products, and the female attraction for male beetles.

The Japanese beetle (*Popillia japonica* Newman) feeds on almost 300 species of plants, but it is particularly attracted to certain species of the Aceraceae, Anacardiaceae, Ericaeae, Fagaceae, Gramineae, Hippocastanaceae, Juglandaceae, Lauraceae, Leguminosae, Liliaceae, Lythraceae, Malvaceae, Onagraceae, Platanaceae, Polygonaceae, Rosaceae, Salicaceae, Tiliaceae, Urticaceae, and Vitaceae (Hawley and Metzger *1940*).[1]

The beetle is a gregarious insect. Either sex may infest a plant (Smith and Hadley *1926*). When one or more beetles start to feed on a plant, other beetles in the vicinity tend to alight on the plant. Van Leeuwen et al. (*1928*) and Van Leeuwen (*1932*) found that 50 percent more beetles alighted on infested foliage than on uninfested foliage. Enormous populations may build up on certain preferred plants, whereas other plants of the same species in the vicinity may be only lightly populated. Where beetles are abundant, they often gather in large numbers on the fruit of early-ripening varieties of apples and peaches and continue to feed until only the core or pit remains. Hawley and Metzger (*1940*) counted 296 beetles on an apple. The "balling" of beetles, although more common on tree fruits, may occur on bush fruits, flowers, and occasionally on foliage.

The population on a plant, however, is never static because the beetle is a restless insect. Beetles move constantly from one location to another on a plant or leave the plant. Van Leeuwen (*1932*) estimated that one-third of the beetles alighting on unsprayed foliage left the plant during the day.

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[1] The year in italic after the authors' names is the key to the references in Literature Cited, p.83.

The beetle prefers fruit infected by disease or damaged by other insects to healthy, sound fruit. The most extensive damage by the insect occurred in neglected orchards (Smith and Hadley *1926*). Peach trees infected by peach yellows and little peach were almost defoliated, whereas adjacent healthy trees were hardly touched by the beetle (Mann *1942*). Apples damaged by the codling moth (*Carpocapsa pomonella* (Linnaeus)) and peaches infected by brown rot were attacked first. When this fruit had been consumed, the beetles fed on healthy fruit (Smith and Hadley *1926*; Fleming and Metzger *1936*).

Normally the beetle attacks fruit on only those varieties of grapes that ripen during the summer. The beetles attacked the fruit of all varieties of grapes infested by the grape berry moth (*Paralobesia viteana* (Clemens)) or infected by black rot, even when the fruit was immature, and then they fed on adjacent sound berries (Fleming and Maines *1947*).

The odor of fermenting fruit on the ground or on the plants is a powerful attractant for the beetles. It was practically impossible to protect early-ripening fruit with the insecticides available prior to DDT unless the decaying fruit was removed or buried. Fleming (*1955, 1960, 1963*) recommended good sanitation in orchards and vineyards to protect fruit from beetle attack.

Smith and Hadley (*1926*) observed that male beetles definitely moved to plants on which females were feeding. The attraction could be the opposite sex and the odor of the lacerated fruit and foliage. Under certain conditions female beetles emerging from the ground were highly attractive to the males.

Early in the summer when beetles began to emerge in large numbers on a golf course in a heavily infested area, many males were seen early in the morning of clear, warm days flying low over the turf in search of female beetles. As a female emerged from the ground, many males alighted and attempted to copulate before she could fly. The males alighted on the ground 4 to 6 inches on the leeward side of the female and crawled rapidly toward her. They always approached a female against the wind. As the direction of the wind shifted, the trail of beetles changed accordingly. Copulation rarely took place when many males were competing for a female. In 1922 within a 25-square yard area on the golf course, 78 "balls" of beetles were observed at one time. Each "ball" contained a single female and from 25 to 200 males. Fleming (*1960, 1963*) reported that as many as 300 males had been found clustered about a single female. The "balling" ceased at midday and did not occur again until another favorable morning. It rarely occurred later than 2 or 3 weeks after the initial emergence of the beetle in an area.

The investigation of attractants was undertaken in 1919, when some essential oils and certain fruity and fermentation odors were found to be attractive to the beetle (Davis *1920a*). Some phases of the investigation were conducted cooperatively by the Japanese Beetle Laboratory, other Federal agencies, and State agricultural experiment stations within the beetle-infested area. Progress reports on the investigation appeared from time to time in Federal and State publications and in various scientific journals. However, much additional information is found in the unpublished progress reports by O. G. Anderson, F. J. Brinley, E. D. Burgess, R. D. Chisholm, W. E. Fleming, H. L. Haller, H. A. Jones, L. Koblitsky, T. L. Ladd, N. E. McIndoo, W. W. Maines, F. E. Mohrhof, C. W. Mell, E. G. Rex, E. A. Richmond, L. B. Smith, P. A. Vander Meulen, and E. R. Van Leeuwen, and in the unpublished quarterly and annual reports of the Japanese Beetle Laboratory by C. H. Hadley and W. E. Fleming on file at the laboratory. These published and unpublished records have been reviewed here so that information on attractants for the beetle during 1919–64[2] might be more available to other entomologists and the general public.

ODORIFEROUS CONSTITUENTS OF PLANTS AND OTHER CHEMICALS

Nature of Attractive Odors

Metzger et al. (*1934*) determined the amount of sugar in the foliage and sometimes in the fruit of 97 species and varieties of plants and the odor of the clarified alcoholic extracts. The amount of reducing sugar as dextrose per gram of plant material ranged from 0.4 to 30 mg., as shown in the following data:

Sugar in foliage (mg. per gram)	*Plants attacked (percent)*
Less than 5	19
5–10	50
10–15	47
15–20	53
20–25	70
25–30	85

Thirty-nine extracts had an ethereal or fruity odor; 22 were fragrant, five aromatic, and three empyreumatic; 10 had various odors and 18 no distinctive odor. Of the plants having extracts with a fruity odor, the beetles damaged severely 47 percent of those with a sugar content up to 15 mg. and 71 percent of those with 15 to 30 mg. Of the plants without a fruity odor, the percentages were 18 and 22, respectively. Sugar content and odor were important factors in the susceptibility of a plant to beetle attack. Unfortunately the substances causing the fruity odor were not identified.

[2] Although the data on which this bulletin is based were collected during 1919–64, the findings are still valid and useful as guidelines for developing research needed to prevent losses from insect attack.

Little information is available on the odoriferous constituents of plants. Smith (*1924*) and Smith and Hadley (*1926*) reported that a series of preferred plants had been analyzed and all contained geraniol in varying quantities. The plants were not identified. Power and Chestnut (*1922*) found geraniol in the parings of ripe McIntosh apples, one of the most fragrant varieties, and stated that geraniol, either in the free state or as esters, probably is contained in varying quantities in all ripe apples. Power and Kleber (*1896*) found that the oil from sassafras leaves contained geraniol but no eugenol.

Langford et al. (*1943*) reported that the following odoriferous chemicals, which most frequently occur in combination with each other and with other constituents of plants, had been isolated from the ripe fruits of apple and peach, the foliage of sassafras, and the flowers of rose:

Chemical	*Isolated from—*
Acetic acid	Apple, peach, rose, and sassafras.
Benzaldehyde	Apple and peach.
Caproic acid	Apple.
Citral	Apple and rose.
Citronellol	Rose.
Eugenol	Rose and sassafras.
Geraniol	Apple, rose, and sassafras.
Linalool	Peach, rose, and sassafras.
Phenyl ethyl alcohol	Rose.
Valeric acid	Apple, peach, and sassafras.

Major and Tietz (*1962*) demonstrated the importance of odor in the beetle's preference for certain plants. *Ginkgo biloba* L. is not usually attacked by the beetle. Beetles confined with fresh foliage usually died rather than eat the leaves. When the leaves were coated with juice pressed from cherry leaves, the beetles ate the coated *Ginkgo* leaves readily without any harmful effect. Cherry leaves coated with juice from *Ginkgo* leaves were eaten about as readily as uncoated cherry leaves. *Ginkgo* leaves coated with eugenol or valeric acid in glycerin were eaten extensively. It was evident that *Ginkgo* was not repellent or poisonous to the beetles but lacked odoriferous substances attractive to them.

Screening Tests

The search for a good beetle attractant involved the trial-and-error testing of many substances, alone and in combinations. McIndoo (*1931*) reviewed some of the early tests with attractants.

Olfactometer Tests

McIndoo (unpublished), using an olfactometer similar to one described in his (*1926*) experiments with the Colorado potato beetle (*Leptinotarsa decemlineata* (Say)), tested the chemotropic response of the beetle to several odoriferous chemicals in 1924. The olfactometer consisted essentially of a glass Y-tube with an inside diameter of 0.5 inch, a stem 2 inches long, and forks 6 inches long. The stem was connected to a dark bottle in which beetles were placed at the beginning of a test. The apparatus was placed with the forks directed toward light. Cotton saturated with 0.5 ml. of a test substance was placed in the open end of one fork and untreated cotton or cotton saturated with 0.5 ml. of ethyl alcohol in the other fork. The suction apparatus, which drew air at approximately 10 gallons per hour from the chemicals to an orifice at the junction of the forks, was started and beetles were released one at a time from the dark bottle. When the temperature was less than 80° F., the beetles did not respond to either light or odor. At 85° about 75 percent of the beetles moved from the dark bottle into the stem of the Y-tube, where they had a choice of moving into either fork. A test was completed in about 15 minutes.

All the undiluted test substances were highly repellent to the beetles; usually 90 percent of them moved into the fork with no chemical. The concentration of the substances was reduced by diluting them with ethyl alcohol. At a dilution of 1:5,000, a 0.5-ml. quantity of most alcoholic solutions was slightly more attractive than ethyl alcohol. Of the beetles responding, 60 to 68 percent of them went to the fork containing citral, clove oil, geraniol, or sassafras oil; 51 to 59 percent to the fork containing citronella oil or eugenol; and less than 50 percent to the fork containing lemon oil, linalool, pinene, or safrol. The replicated tests were not always consistent. The differences in the response of the beetles to these odors were small and not sufficient to establish their relative effectiveness.

Metzger (unpublished) constructed in 1927 several olfactometers, which were large enough for the beetles to walk and fly freely in them. The best one was a tight box 4 feet long, 16¼ inches wide, and 16¼ inches high, with glass on the sides, ends, and top. Air was introduced through a No. 60 orifice (diameter not given) at each end of the box and was withdrawn at the central point in the top. The air flowed through these inlets at 0.025 and 0.035 cubic foot per minute when the pressure in the box was reduced by 1 and 2 inches of mercury, respectively. A glass baffle was placed in front of each inlet to disperse the air. To study the pattern of movement in the box, air was bubbled at the latter rate through ammonium hydroxide for several minutes and introduced into one end of the box. Then the ammonium hydroxide was replaced with hydrochloric acid. The reaction of these chemicals produced ammonium chloride, which was readily visible in the air. During the first 30 minutes the ammonium chloride was confined to the half of the box where the chemicals were introduced, but gradually it spread throughout the box.

Air bubbled through geraniol and through 50, 25, and 10 percent dilutions of geraniol and ethyl alcohol was introduced at one end of the box and air bubbled through water was introduced at the opposite end. A few minutes later the beetles were introduced at the center of the box. Within 30 minutes they had gathered at the end of the box where the air was being bubbled through water, showing that geraniol and the alcoholic solutions were repellent under these conditions. In view of this reaction of the beetle to geraniol, a known attractant, the olfactometer did not seem promising for a survey of the attractiveness of various substances and further tests were discontinued.

Unfortunately further tests were not conducted with such a potentially useful device as an olfactometer for the preliminary survey of the attractiveness of various substances to the beetle. Much time and effort could have been saved if only substances known to be attractive had been tested in the field. Possibly if the air had been passed over a small wick saturated with geraniol, the evaporating surface of the wick could have been adjusted so that the amount of geraniol in the air would have been attractive to the insect. Adequate control of the temperature, relative humidity, and light would have made the replicated tests more consistent.

Bait Can Tests in Field

Method.—Brinley (unpublished) demonstrated that beetles could be attracted from foliage to crushed ripe apples or peaches in cans but not to crushed pears, a fruit not favored by them. As a result, he introduced in 1923 the bait can method of testing the attractiveness of odoriferous substances to the beetle. The method was improved by Richmond (*1927*, *1931*).

The odoriferous substance was mixed with sweetened bran (50 grams of bran, 4.5 grams of molasses, and 4.5 grams of glycerin), placed in 4-ounce perforated cans, and suspended from limbs of trees in infested orchards. Five cans of each bait were hung on different trees and tested in competition with other baits. Eight baits, including one of only sweetened bran, were hung on a tree. No standard odoriferous bait was included in the series of tests. The beetles were removed from the baits six or more times daily and the numbers taken from each can were recorded.

Often the numbers of beetles removed from the five cans of a bait during a day and from day to day differed greatly because of the heterogeneity of the beetle population throughout a tree and from tree to tree in an orchard. Since there was no standard odoriferous bait in each tree and the sweetened bran was only mildly attractive, it was not possible to adjust for the different numbers of beetles attracted to a bait in different trees. The results with even the eight baits in a series were not strictly comparable because all the baits were not on the same trees. However, when a bait consistently attracted more beetles than its competing baits, it was evident that it was superior to the others. Although this procedure was effective in separating the more attractive substances from those only mildly attractive or nonattractive, it was inadequate for establishing definitely the relative attractiveness of substances within these categories.

Results of Tests.—Some of the results of tests with bait cans have been published by Richmond (*1927, 1931*), but most of them are in unpublished progress reports by F. J. Brinley, F. W. Metzger, E. A. Richmond, and L. B. Smith. Most of the essential oils tested had little attraction to the beetle. Oils that were poor attractants were almond (bitter), almond (sweet), anise seed, banana, bergamot, cade, cajeput, cassia, cedar leaf, cedar wood, coriander, croton, eucalyptus, fennel, ginger, hemlock, lavender, lemon, mustard, orange, pennyroyal, peppermint, pine, rose geranium, rue, sage, spearmint, thyme, wintergreen, and wormseed. The beetle was definitely attracted to the citronella, clove, lemongrass, palmarosa, sassafras, and tansy oils.

Tests with some of the constituents of the essential oils indicated little attraction to iso-eugenol, the geraniol sesquiterpenes, limonene, linalyl acetate, methyl salicylate, phellandrene, diphenyl ether, piperonal, safrole, or vanillin. The beetle was definitely attracted to citral, citronellal, citronellol, eugenol, eugenol methyl ether, geraniol, and geranyl acetate.

Acetic acid was mildly attractive, but succinic acid was nonattractive. There was little attraction to the following alcohols: Allyl, amyl, iso-amyl, benzyl, n-butyl, iso-butyl, capryl, cinnamic, ethyl, n-heptyl, methyl, phenyl, and iso-propyl. Amyl acetate, ethyl acetate, ethyl formate, and methyl butyrate were only mildly attractive.

Smith (*1924, 1924a*) reported that tests during the summer of 1923 had demonstrated that some of the higher alcohols and phenols in low concentration were attractive to the beetle. Geraniol and the essential oils containing that alcohol were especially attractive for the beetle. This claim was not substantiated by later investigators, who found that many species of insects were attracted by the alcohol. Probably he came to that conclusion because the bait cans were operated in heavily infested orchards and under these conditions few insects other than the beetle came to the cans.

Richmond (*1927*) considered geraniol to be the primary attractant for the beetle. To substantiate this claim he cited tests where various baits had attracted the following numbers of beetles: Geraniol 10,071, eugenol 1,562, citronellal 1,214, citral 1,034, citronellol 620, and diphenyl ether 146. These data indicated that the relative attractiveness (percent) was geraniol 100, eugenol 16, citronellal 12, citral 10, citronellol 6, and diphenyl ether 1. The data indicated that these comparisons were not valid, because the concentration of the chemicals per bait ranged from 0.25 gram for eugenol to 5 grams for geraniol and the selected tests were not all made at the same time. In the unpublished report by L. B. Smith and E. A. Richmond where additional data are presented, only geraniol and eugenol had been tested at the same concentration in one series and geraniol and citral in another. In these tests the relative attractiveness of the compounds appeared to be geraniol 100, eugenol 58, and citral 31 percent. No doubt geraniol was the best attractant of those tested, but it was not as superior to the other compounds as indicated in the published report.

To protect the use of geraniol as an attractant for insects, particularly the Japanese beetle, U.S. Patent 1,572,568 was granted to L. B. Smith, E. A. Richmond, and P. A. Vander Meulen in 1926. It was assigned to the Secretary of Agriculture. (Smith et al. *1926*)

Tests With Baited Traps in Field

Methods.—Van Leeuwen and Metzger (*1930*) improved the method of testing in 1928 by placing the baits in traps hung on stakes 4 feet above the ground between rows of trees in infested orchards. Each series included five experimental baits and a standard 10:1 geraniol-eugenol bait and was replicated three to five times. After each daily collection of beetles from the traps, each trap in a series was moved to a new position, for example, trap 1 to position 6 and trap 2 to position 1, in an attempt to compensate for differences in the beetle population at the various positions. The numbers of beetles captured by traps with the experimental and the standard geraniol-eugenol baits were compared. The attractiveness of an experimental bait was expressed as a percentage of that of the standard bait.

The same experimental design, placing traps 10 feet apart in rows in an open field, was used by Langford and Cory (*1964*), Langford and Gilbert (*1949*), Langford et al. (*1943*), and Muma et al. (*1944, 1945*). Each series included three or four experimental baits, an empty trap, and the standard geraniol-eugenol bait and was replicated three times. After each daily collection of beetles, each trap was moved to a new position in the series. The effectiveness of an experimental bait was expressed as a percentage of that of the standard.

Metzger (*1930*) and Metzger and Maines (*1935*) paired each trap containing an experimental bait with one containing the geraniol-eugenol standard. The paired traps were hung on stakes 4 feet above the ground and 2½ feet apart. The pairs of traps were 10 feet apart in rows in an open field. Each experimental bait was replicated five times. The attractiveness of each experimental bait was expressed as a percentage of that of the standard bait.

Fleming and Burgess (*1940*) and Fleming et al. (unpublished) arranged the baited traps in an open field in a Latin square design. The basic principle of this design is to have the same number of traps in each row and column of the square and to have each row and column contain a complete series of baits. A 5 by 5 Latin square was adopted as the experimental unit because the distribution of beetles was less heterogeneous throughout a square of that size than in larger squares. Each Latin square contained the geraniol-eugenol standard bait and four experimental baits. The traps were hung 4 feet above the ground on stakes placed 20 feet apart in the rows and columns. The attractiveness of each experimental bait was expressed as a percentage of that of the standard bait.

The relative attractiveness of an experimental bait and the geraniol-eugenol standard could be satisfactorily evaluated with each of these experimental designs.

A 10:1 mixture of technical geraniol and U.S.P. eugenol was used as the standard bait at the Japanese Beetle Laboratory from 1928 to 1941. The University of Maryland used a 9:1 mixture of these components as the standard bait. There was no significant difference in the attractiveness of these standard baits. The geraniol-eugenol mixture is not an ideal standard, because technical geraniol, a complex mixture of several components, varied to some extent in its attractiveness from batch to batch. On the other hand, U.S.P. eugenol is practically a pure compound and more constant in its attractiveness from batch to batch.

Fleming et al. (unpublished) established in 1940 and 1941 that redistilled eugenol obtained from clove oil attracted about 70 percent as many beetles as most of the 10:1 geraniol-eugenol mixtures. From 1941 to 1964, redistilled U.S.P. eugenol has been the standard bait at the Japanese Beetle Laboratory. To make comparable evaluations with the eugenol and geraniol-eugenol standards, the number of beetles attracted by the former was multiplied by 1.43.

Results of Tests.—Since the beetle is strongly attracted to the ripening fruits of apple, apricot, cherry, grape, and peach, commercial flavors of these fruits were expected to be good attractants, but the beetle's reaction to the flavors was disappointing. Van Leeuwen (unpublished) in 1930 found that the flavors of apricot, cherry, grape, and peach attracted less than 12 percent as many beetles as the standard bait. Langford et al. (*1943*) found the relative attractiveness of apple flavor was only 12 percent.

A summary was prepared of the relative attractiveness of 334 experimental baits composed of essential oils and various odoriferous chemicals, alone and in mixtures, in competition with the geraniol-eugenol standard. The tabulation shows the composition of each experimental bait by volume, its average relative attractiveness in parenthesis, and the source of information. The data were grouped according to relative attractiveness: Less than 25, 25–75, 76–125, 126–200, and more than 200 percent.

BAITS ATTRACTING LESS THAN 25 PERCENT AS MANY BEETLES AS GERANIOL–EUGENOL STANDARD

Composition of bait and relative attractiveness (percent)[1]	*Source*
Acetic acid (glacial) (3)	Langford et al. *1943*.
Acetophenone + eugenol 9:1 (18)	Fleming et al. unpub.
Amyl acetate (8)	Langford et al. *1943*.
iso-Amyl benzene ether + eugenol 9:1 (11)	Fleming et al. unpub.
Amyl salicylate + eugenol 9:1 (20)	Do.
iso-Amyl valerate (4)	Do.
Anethole (from anise oil) (8)	Do.
Anethole + caproic acid 9:1 (12)	Langford and Cory *1946*.
Anethole (from pine oil) (16)	Fleming et al. unpub.
Anethole + bay oil + dimethylphthalate 3:1:4 (18)	Do.
Anise oil (3)	Do.
Anise oil + eugenol 9:1 (19)	Do.
Apple oil (synthetic) (9)	Do.
"Arcol" (15–20 percent and methyl chavicol) + eugenol 9:1 (15), 4:1 (13)	Do.
"Arcol" + pimenta oil 4:1 (13)	Do.
Bay oil (19)	Langford et al. *1943*.
Benzaldehyde (6)	Do.
Benzophenone (5 grams in 20 ml. dimethylphthalate) (7)	Fleming et al. unpub.
Benzophenone + eugenol 9:1 (21)	Do.
Benzyl ether (2)	Do.
n-Butylamine (4)	Do.
Butyl sorbate (2)	Tashiro et al. *1964*.
Butyl sorbate + ethyl alcohol 1:1 (1)	Do.
Butyric acid (13)	Fleming et al. unpub., Langford et al. *1943*.
n-Butyric acid (4)	Fleming et al. unpub.
iso-Butyric acid (5)	Do.
gamma Cadinene (11)	Do.
Calamus oil (6)	Langford et al. *1943*.
Camphor oil (3)	Do.
Caraway oil (4)	Do.
Cassia oil (16)	Fleming et al. unpub.
Cedar wood oil (3)	Langford et al. *1943*.
Citral (20)	Metzger unpub., Langford et al. *1943*.
Citronella terpenes (4)	Fleming et al. unpub.

Citronellal (14)	Metzger and Maines *1935*, Langford et al. *1943*, Fleming et al. unpub.
Citronellol (16)	Langford et al. *1943*.
d-Citronellol (22)	Fleming et al. unpub.
1-Citronellol (12)	Do.
Citronyl acetate (7)	Do.
Clove oil (19)	Langford et al. *1943*, Fleming et al. unpub.
Copaiba oil (2)	Langford et al. *1943*.
Coriander oil (24)	Do.
Corn oil (5)	Do.
Coumarin (5 grams in 20 ml. dimethylphthalate) (5)	Fleming et al. unpub.
Cymene (3)	Do.
Elemol + eugenol 9:1 (20)	Do.
Eucalyptus oil (2)	Langford et al. *1943*.
iso-Eugenol (6)	Fleming et al. unpub.
Fenchyl alcohol + eugenol 9:1 (13)	Do.
Fennel oil (3)	Do.
Fish oil (5)	Do.
Formic acid (3)	Langford et al. *1943*.
Furfural (3)	Do.
Geraniol C.P. (20)	Fleming et al. unpub.
Geraniol C.P. + d-citronellol 1:1 (17)	Do.
Geraniol C.P. + geranyl acetate 1:1 (16)	Do.
Geraniol C.P. + methyl anthranilate 9:1 (10)	Do.
Ginger oil (7)	Langford et al. *1943*.
Grapefruit oil (7)	Fleming et al. unpub.
Grape juice (8)	Do.
Heptaldehyde (21)	Do.
Lavender flowers oil (3)	Langford et al. *1943*.
Lemongrass oil (13)	Do.
Lemon oil (natural) (7)	Do.
Lemon oil (synthetic) + eugenol 9:1 (20)	Fleming et al. unpub.
Linaloe oil (9)	Langford et al. *1943*.
Linalool (7)	Do.
Methyl alcohol (2)	Fleming et al. unpub., Langford et al. *1943*.
Methyl anthranilate + eugenol 9:1 (16)	Fleming et al. unpub.
Methyl salicylate (8)	Langford et al. *1943*.

See footnote at end of tabulation.

BAITS ATTRACTING LESS THAN 25 PERCENT AS MANY BEETLES AS GERANIOL—EUGENOL STANDARD—CONTINUED

Methyl salicylate + eugenol 9:1 (20)	Fleming et al. unpub.
Mineral oil + deobase oil 1:1 (6)	Muma et al. *1944*.
Neroli oil (4)	Langford et al. *1943*.
allo-Ocimene + eugenol 9:1 (18)	Fleming et al. unpub.
Oleic acid (4)	Do.
Orange oil (natural) + eugenol + dimethylphthalate 3:1:4 (18)	Do.
Orange oil (natural) + peach aldehyde + dimethylphthalate 1:1:8 (3)	Do.
Palmitic acid (15)	Langford et al. *1943*.
Peach aldehyde + dimethylphthalate 1:9 (4)	Fleming et al. unpub.
Peach aldehyde + eugenol + dimethylphthalate 1:1:8 (19)	Do.
di-Pentene (9)	Do.
Peppermint oil (3)	Langford et al. *1943*.
Perilla oil (4)	Fleming et al. unpub.
2-Phenyl benzothiazole + mineral oil 1:9 (10)	Metzger unpub.
Phenyl ethyl acetate (5)	Fleming et al. unpub.
Phenyl ethyl alcohol (23)	Langford et al. *1943*, Metzger unpub.
di-Phenyl methane + eugenol 9:1 (20)	Fleming et al. unpub.
di-Phenyl oxide + eugenol 9:1 (20)	Do.
Pinene (4)	Langford et al. *1943*.
Pine oil (2)	Do.
Pine oil + eugenol 9:1 (17)	Fleming et al. unpub.
Rose geranium oil (15)	Fleming et al. unpub., Langford et al. *1943*.
Safrole (5)	Do.
Sandlewood oil (4)	Langford et al. *1943*.
Sassafras oil (natural) (19)	Langford et al. *1943*, Fleming et al. unpub., Metzger unpub.
Sassafras oil (synthetic) (21)	Fleming et al. unpub., Metzger unpub.
Sassafras oil (synthetic) + eugenol 9:1 (13)	Fleming et al. unpub.
Stearic acid (4)	Langford et al. *1943*.
alpha Terpineol (23)	Fleming et al. unpub.
beta Terpineol (16)	Do.
beta Terpineol + eugenol 9:1 (18)	Do.
Vanillin (2)	Do.
Vinegar (5 percent acetic acid) (15)	Langford et al. *1943*.
Wintergreen oil (4)	Do.
Ylang ylang oil (6)	Do.

BAITS ATTRACTING 25–75 PERCENT AS MANY BEETLES AS GERANIOL–EUGENOL STANDARD

iso-Amyl valerate + eugenol 9:1 (53)	Fleming et al. unpub.
iso-Amyl valerate + eugenol + dimethylphthalate 3:1:4 (27)	Do.
Anethole + bay oil 9:1 (37), 4:1 (33), 3:1 (27)	Do.
Anethole + caproic acid 1:1 (58)	Langford and Cory *1946*.
Anethole + clove oil 9:1 (58), 4:1 (51), 3:1 (55)	Fleming et al. unpub.
Anethole + clove oil + dimethylphthalate 3:1:4 (26)	Do.
Anethole + eugenol + dimethylphthalate 3:1:4 (71)	Do.
Anethole + geraniol 9:1 (51), 1:9 (29)	Muma et al. *1945*, Fleming et al. unpub.
Anethole + pimenta oil + dimethylphthalate 3:1:4 (64)	Fleming et al. unpub.
Bay oil + phenyl ethyl alcohol 1:9 (64)	Do.
Bay oil + pimenta oil 1:1 (44)	Langford et al. *1943*.
Bay oil + sassafras oil 1:1 (31)	Do.
Butyl carbitol acetate + eugenol 9:1 (27)	Fleming et al. unpub.
Caproic acid (27)	Langford et al. *1943*, Fleming et al. unpub.
Caproic acid + eugenol 9:1 (61), 4:1 (53)	Fleming et al. unpub.
Caproic acid + pimenta oil 1:1 (72)	Langford et al. *1943*.
Caproic acid + sassafras oil 1:1 (49)	Do.
iso-Caproic acid (35)	Fleming et al. unpub.
n-Caproic acid (25)	Do.
Cinnamic aldehyde + phenyl ethyl alcohol 9:1 (41)	Do.
Citral + eugenol 10:1 (67), 9:1 (71)	Metzger unpub., Fleming et al. unpub., Muma et al. *1945*.
Citral + eugenol + geraniol 90:1:9 (72)	Muma et al. *1945*.
Citral + geraniol 9:1 (37), 1:9 (51)	Fleming et al. unpub., Muma et al. *1945*.
Citronella oil + clove oil + phenyl ethyl alcohol 18:1:1 (69)	Langford et al. *1943*.
Citronellal + eugenol 10:1 (45)	Metzger and Maines *1935*.
Clove oil + phenyl ethyl alcohol 1:9 (50)	Fleming et al. unpub.
Clove oil + phenyl ethyl alcohol + pimenta oil 18:1:1 (34)	Langford et al. *1943*.
Coumarin (5 grams in 20 ml. dimethylphthalate) + eugenol 9:1 (31)	Fleming et al. unpub.
Crystox 5 grams + eugenol 2.5 grams + acetone to 25 ml. (58)	Do.
Ethyl caproate + eugenol + mineral oil 9:2:9 (58)	Muma et al. *1945*.
Ethyl caproate + geraniol + mineral oil 9:2:9 (69)	Do.
Eugenol C.P. (70)	Fleming et al. unpub.
Eugenol U.S.P. (from cinnamon oil) (64)	Do.
Eugenol U.S.P. (from clove oil) (68)	Fleming et al. unpub., Langford and Cory *1946*.
Eugenol U.S.P. + dimethylphthalate 1:3 (35)	Fleming et al. unpub.
Eugenol U.S.P. + ethylene glycol 4:1 (68), 3:2 (66), 2:3 (62), 1:4 (51), 1:9 (38)	Do.

BAITS ATTRACTING 25–75 PERCENT AS MANY BEETLES AS GERANIOL–EUGENOL STANDARD—CONTINUED

Fenchone + eugenol + dimethylphthalate 3:1:4 (42)	Do.
Fennel oil + eugenol 9:1 (35)	Do.
Geraniol C.P. + acetophenone 9:1 (32)	Do.
Geraniol C.P. + amyl salicylate 9:1 (49)	Do.
Geraniol C.P. + citral 9:1 (51)	Do.
Geraniol tech. + acetic acid 99:1 (72), 10:1 (47)	Do.
Geraniol tech. + bay oil 9:1 (63)	Do.
Geraniol tech. + benzaldehyde 199:1 (66)	Do.
Geraniol tech. + citric acid 50:1 (50)	Do.
Geraniol tech. + ethylene glycol 50:1 (43)	Do.
Geraniol tech. + eugenol + dimethylphthalate 9:1:10 (74)	Do.
Geraniol tech. + eugenol + mineral oil + deobase oil 27:3:35:35 (63), 9:1:20:20 (56), 9:1:45:45 (48)	Muma et al. *1944*.
Geraniol tech. + eugenol + phenyl ethyl acetate 1:2:8 (72)	Langford and Gilbert *1949*.
Geraniol tech. + eugenol + plum leaf oil (synthetic) 10:1:10 (68)	Metzger unpub.
Geraniol tech. + eugenol + sassafras oil (natural) 10:1:10 (28)	Do.
Geraniol tech. + eugenol + sassafras oil (synthetic) 10:1:10 (72)	Do.
Geraniol tech. + lactic acid 50:1 (56)	Fleming et al. unpub.
Geraniol tech. + phosphoric acid 199:1 (71)	Do.
Geraniol tech. + safrole 10:1 (40)	Do.
Geraniol tech. + thymol 10:1 (53)	Do.
Geraniol tech. + triethanolamine 199:1 (72)	Do.
Geraniol tech. + vanillin 199:1 (26)	Do.
Geraniol tech. (hydrogenated) (38)	Do.
Geranyl acetate (36)	Metzger and Maines *1935*, Metzger unpub., Fleming et al. unpub.
Geranyl acetate + eugenol 10:1 (75)	Metzger and Maines *1935*, Metzger unpub.
Grapefruit oil + eugenol + dimethylphthalate 3:1:4 (40)	Fleming et al. unpub.
Lemon oil (natural) + eugenol 9:1 (37)	Langford et al. *1943*.
Limonene + eugenol 9:1 (54)	Fleming et al. unpub.
p-Methylacetophenone + eugenol 9:1 (45)	Do.
di-Methyl tolyl carbinol + eugenol 9:1 (47)	Do.
Myrcene + eugenol 9:1 (48)	Do.
4–6 di-Nitro-m-cresol methyl ether 10 grams + eugenol 5 grams + acetone to 50 ml. (46)	Do.
Orange oil (natural) + eugenol 9:1 (60)	Do.
Orange oil (synthetic) + eugenol 9:1 (55)	Do.
Palmarosa oil (66)	Do.

Peach aldehyde + phenyl ethyl alcohol + dimethylphthalate 1:5:4 (49)	Do.
Phenyl cellosolve + eugenol 9:1 (50)	Do.
Phenyl ethyl alcohol + eugenol 10:1 (58), 9:1 (74)	Metzger unpub., Fleming et al. unpub.
Phenyl ethyl butyrate + eugenol + mineral oil 9:2:9 (62)	Muma et al. *1945*.
Pimenta oil (54)	Langford et al. *1943*.
Pimenta oil + ethyl alcohol 1:1 (64)	Do.
Pimenta oil + phenyl ethyl alcohol 1:9 (48)	Fleming et al. unpub.
Pimenta oil + propionic acid 1:4 (43)	Langford et al. *1943*.
Pimenta oil + sassafras oil (natural) 1:1 (57)	Do.
Pimenta oil + valeric acid 1:9 (68)	Do.
alpha Pinene pyrolysate + eugenol 9:1 (49)	Fleming et al. unpub.
beta Pinene pyrolysate + eugenol 9:1 (46)	Do.
Plum leaf oil (synthetic) (35)	Metzger unpub.
Propionic acid (33)	Langford et al. *1943*.
Rhodinol + dimethylphthalate 1:4 (28)	Fleming et al. unpub.
Safrole + eugenol 9:1 (32)	Do.
Sassafras oil (natural) + bay oil + caproic acid 18:1:1 (51)	Langford et al. *1943*.
Sassafras oil (natural) + eugenol 9:1 (51)	Fleming et al. unpub., Langford et al. *1943*.
Sassafras oil (natural) + eugenol + dimethylphthalate 3:1:4 (50)	Fleming et al. unpub.
Sesquiterpene alcohols (55)	Metzger and Maines *1935*, Fleming et al. unpub.
Sesquiterpene alcohols + eugenol 10:1 (69)	Metzger and Maines *1935*.
alpha-Terpineol + eugenol 9:1 (32)	Fleming et al. unpub.
Valeric acid (29)	Fleming et al. unpub., Langford et al. *1943*.
Valeric acid + bay oil 9:1 (75)	Langford et al. *1943*.
Valeric acid + linaloe oil 1:1 (55)	Do.
Valeric acid + pimenta oil 9:1 (68)	Do.
Valeric acid + sassafras oil (natural) 9:1 (69)	Do.

BAITS ATTRACTING 76–125 PERCENT AS MANY BEETLES AS GERANIOL–EUGENOL STANDARD

Anethole + caproic acid + citronella oil + phenyl ethyl butyrate + iso-valeric acid 8:8:3:3:8 (113)	Langford and Cory *1946*.
Anethole + caproic acid + phenyl ethyl butyrate 6:3:1 (76), 9:9:2 (95)	Langford and Cory *1946*, Fleming et al. unpub.
Anethole + caproic acid + phenyl ethyl butyrate + iso-valeric acid 4:4:3:4 (120)	Langford and Cory *1946*.
Anethole + eugenol 19:1 (115), 9:1 (101), 4:1 (106), 3:1 (121), 3:2 (97), 1:1 (77), 2:3 (83)	Fleming and Chisholm *1944*, Fleming et al. unpub., Langford and Cory *1946*, Muma et al. *1945*.

BAITS ATTRACTING 76–125 PERCENT AS MANY BEETLES AS GERANIOL–EUGENOL STANDARD—CONTINUED

Anethole + eugenol + geraniol 90:1:9 (77)	Muma et al. *1945*.
Anethole + eugenol + geraniol + phenyl ethyl butyrate 12:1:1:1 (114)	Langford and Cory *1946*.
Anethole + eugenol + phenyl ethyl butyrate 18:1:1 (114), 8:1:1 (84)	Do.
Anethole + eugenol + phenyl iso-valerate 8:1:1 (88)	Do.
Anethole + eugenol + iso-valeric acid 9:1:40 (79)	Do.
Anethole + pimenta oil 9:1 (105), 4:1 (105), 3:2 (101), 2:3 (113)	Fleming and Chisholm *1944*, Fleming et al. unpub.
Caproic acid + eugenol + geraniol + mineral oil 9:1:1:9 (93), 45:1:9:45 (104)	Muma et al. *1945*, Langford and Cory *1946*.
Caproic acid + eugenol + mineral oil 9:2:9 (81)	Muma et al. *1945*.
Caproic acid + geraniol 1:4 (103)	Langford and Cory *1946*.
Caproic acid + geraniol + mineral oil 9:1:10 (79), 9:2:9 (107)	Muma et al. *1945*.
Caproic acid + phenyl ethyl butyrate 4:1 (124)	Langford and Cory *1946*.
Caproic acid + phenyl ethyl butyrate + mineral oil 2:1:2 (77), 1:1:2 (106)	Do.
Caproic acid + phenyl ethyl butyrate + phenyl iso-valerate 18:1:1 (78)	Do.
Citronella oil (Ceylon) + eugenol 10:1 (121)	Metzger unpub.
Citronella oil (Java) (77)	Fleming et al. unpub.
Citronella oil (Java) + eugenol 10:1 (121)	Metzger unpub.
Citronella oil (Java) + eugenol + geraniol 5:1:5 (124)	Do.
Citronella oil (Java) + eugenol + phenyl ethyl alcohol 20:2:1 (114)	Do.
Citronellol + eugenol 10:1 (90), 9:1 (77)	Metzger and Maines *1935*, Langford and Cory *1946*.
Ethyl caproate + eugenol + geraniol 18:1:1 (91)	Langford and Cory *1946*.
Ethyl caproate + eugenol + geraniol + mineral oil 45:1:9:45 (80)	Muma et al. *1945*.
Fenchone + eugenol 9:1 (85)	Fleming et al. unpub.
Geraniol C.P. + butyl carbitol acetate 9:1 (96)	Do.
Geraniol C.P. + eugenol 10:1 (103), 9:1 (104)	Do.
Geraniol C.P. + methyl salicylate 9:1 (86)	Do.
Geraniol C.P. + alpha terpineol 9:1 (99)	Do.
Geraniol tech. (80)	Fleming et al. unpub., Langford et al. *1943*.
Geraniol tech. + acetic acid 199:1 (77)	Fleming et al. unpub.
Geraniol tech. + clove oil 10:1 (98), 9:1 (82)	Do.
Geraniol tech. + eugenol 10:1 (98), 9:1 (100)	Fleming et al. unpub., Fleming and Burgess *1940*, Langford et al. *1943*.
Geraniol tech. + eugenol + dimethylphthalate 27:3:10 (87), 9:1:5 (83), 1:1:2 (96), 1:1:6 (76)	Fleming et al. unpub.
Geraniol tech. + eugenol + ethylene glycol 90:9:11 (82)	Do.
Geraniol tech. + eugenol + methyl heptine carbonate 40:4:1 (112), 20:2:1 (77)	Metzger unpub.

Geraniol tech. + eugenol + mineral oil + deobase oil 81:9:5:5 (90), 36:4:5:5 (84), 63:7:15:15 (98), 27:3:10:10 (103), 9:1:5:5 (98), 18:2:15:15 (90)	Muma et al. *1944*, *1945*, Langford and Cory *1946*.
Geraniol tech. + eugenol + phenyl ethyl acetate 1:1:8 (108)	Langford and Gilbert *1949*.
Geraniol tech. + eugenol + phenyl ethyl alcohol 20:2:1 (123), 10:1:2 (106)	Metzger *1935*, unpub.
Geraniol tech. + eugenol + phenyl ethyl butyrate + mineral oil 9:1:90:100 (84), 9:1:45:45 (96)	Langford and Cory *1946*. Muma et al. *1945*.
Geraniol tech. + eugenol + iso-valeric acid 9:1:40 (79)	Langford and Cory *1946*.
Geraniol tech. + phenyl ethyl acetate 1:4 (84)	Langford and Gilbert *1949*.
Geraniol tech. + phenyl ethyl alcohol 20:1 (90), 10:1 (98), 5:1 (84)	Fleming et al. unpub., Metzger unpub.
Geraniol tech. + phenyl ethyl butyrate + mineral oil 2:9:9 (77)	Muma et al. *1945*.
Geraniol tech. + pimenta oil 9:1 (103)	Fleming and Chisholm *1944*, Fleming et al. unpub.
Grapefruit oil + eugenol 9:1 (84)	Fleming et al. unpub.
Phenyl ethyl acetate + eugenol 8:1 (108), 1:9 (99)	Langford and Gilbert *1949*.
Phenyl ethyl butyrate + eugenol 1:1 (123)	Langford and Cory *1946*.
Phenyl ethyl butyrate + eugenol + mineral oil 9:1:10 (109)	Do.
Pimenta oil + eugenol 9:1 (95)	Langford et al. *1943*.
Rhodinol (109)	Metzger unpub.
Rhodinol + eugenol 10:1 (109)	Do.

BAITS ATTRACTING 126–200 PERCENT AS MANY BEETLES AS GERANIOL–EUGENOL STANDARD

Anethole + caproic acid + eugenol 3:6:1 (176), 2:2:1 (133)	Fleming et al. unpub., Langford and Cory *1946*.
Anethole + caproic acid + eugenol + phenyl ethyl butyrate 12:6:1:1 (144)	Fleming et al. unpub.
Anethole + caproic acid + geraniol 9:9:2 (182)	Langford and Cory *1946*.
Anethole + eugenol + phenyl ethyl acetate 8:1:1 (133)	Langford and Gilbert *1949*.
Caproic acid + eugenol + geraniol 8:1:1 (173)	Langford and Cory *1946*.
Caproic acid + eugenol + geraniol + phenyl ethyl butyrate 12:1:1:1 (178)	Do.
Geraniol + eugenol 5:1 (142), 5:2 (146), 5:4 (165), 1:1 (153)	Fleming and Burgess *1940*, Fleming et al. unpub.
Geraniol + eugenol + ethylene glycol 1:1:2 (169), 1:1:6 (149)	Fleming et al. unpub.
Geraniol + eugenol + mineral oil + deobase oil 7:7:3:3: (140)	Muma et al. *1945*.
Geraniol + eugenol + phenyl ethyl acetate 8:1:1 (130)	Langford and Gilbert *1949*.
Geraniol + eugenol + phenyl ethyl alcohol 10:1:1 (129)	Metzger unpub.
Geraniol + eugenol + phenyl ethyl butyrate 1:1:1 (195), 8:1:1 (144)	Langford and Cory *1946*.
Phenyl ethyl butyrate + eugenol 1:9 (145)	Do.

BAITS ATTRACTING MORE THAN 200 PERCENT AS MANY BEETLES AS GERANIOL–EUGENOL STANDARD

Anethole + caproic acid + eugenol 9:9:2 (246), 6:3:1 (202)	Fleming et al. unpub., Langford and Cory *1946*.
Anethole + caproic acid + eugenol + geraniol + phenyl ethyl butyrate 6:6:1:1:1 (206)	Langford and Cory *1946*.
Anethole + caproic acid + eugenol + phenyl ethyl butyrate 9:9:1:1 (279)	Do.
Anethole + caproic acid + eugenol + phenyl ethyl butyrate + iso-valeric acid 8:8:3:3:8 (285)	Do.
Caproic acid + eugenol + geraniol + phenyl ethyl butyrate 4:1:4:1 (232)	Do.
Caproic acid + eugenol + phenyl ethyl butyrate 8:1:1 (284), 18:1:1 (301)	Do.
Caproic acid + eugenol + phenyl iso-valerate 8:1:1 (264)	Do.
Geraniol + eugenol + phenyl ethyl butyrate 1:1:8 (222)	Do.
Geraniol + eugenol + phenyl iso-valerate 1:1:8 (378)	Do.

[1] Parenthetical numbers in percent unless otherwise indicated.

The screening tests showed that the beetle was attracted to a wide variety of unrelated odoriferous substances, probably because it is cosmopolitan in its choice of food. Of the 334 experimental baits, 106 of them attracted less than 25 percent as many beetles as the geraniol-eugenol standard, 114 from 25 to 75 percent, 84 from 76 to 125 percent, 19 from 126 to 200 percent, and 11 more than 200 percent. Seventy-three of the 90 baits with one component were in the low category, 14 in the second, and three in the third category, approaching the standard bait in attractiveness. The three baits were citronella oil, technical geraniol, and rhodinol— substances closely related. Technical geraniol is a distillation fraction of citronella oil, and rhodinol is a higher aliphatic alcohol with two more hydrogen atoms than pure geraniol.

The 146 binary mixtures were spread over four categories: 29 of them in the low, 74 in the second, 38 in the third, and five in the fourth. Of the 74 mixtures with three components, four were in the low category, 23 in the second, 29 in the third, 11 in the fourth, and seven in the fifth. Three of the 24 mixtures with four or five components were in the second category, 14 in the third, three in the fourth, and four in the fifth.

There were 30 mixtures that were at least 26 percent more attractive than the geraniol-eugenol standard; 11 baits were 26 to 50 percent more attractive, eight baits 50 to 100 percent more attractive, five baits 100 to 150 percent more attractive, and six baits more than 150 percent more attractive. There was ample opportunity to develop more attractive baits than the 10:1 geraniol-eugenol mixture.

Some Factors Modifying Attractiveness of Baits

Activity of Beetle

Fleming (*1963a*) and others have observed that the beetles are most active on warm, clear summer days between 9 a.m. and 3 p.m. standard time. Early in the morning they are usually resting quietly on plants or are in the ground. When the temperature rises above 70° F., they begin to fly in all directions and to collect on the more favored plants in the vicinity. They are most active between 85° and 95°. The beetles become inactive above 95° and often seek shade by crawling to the underside of leaves. A relative humidity above 60 percent retards flying and induces the beetles to feed more extensively. Late in the afternoon flying decreases and the beetles rest on foliage or go into the ground. There is little flying on cool, windy days or on cloudy days and no activity on rainy days. The beetles are very responsive to a change in the intensity of light. A passing cloud will cause a beetle in flight to seek a suitable resting place immediately.

Purity of Products

Most of the tests were made with the technical or commercial grades of the essential oils and chemicals, which usually lack definite specifications of their purity. A technical product from different lots and sources was more likely to vary in its attractiveness than the pure product. The pure products, when available, were often too costly to be used as lures, except experimentally for comparison with the technical products. There was no consistent pattern in the attractiveness of the technical and pure products, as shown in the following examples:

Relative attractiveness (percent) of—

Technical product	*Pure product*
Butyric acid 13	n-Butyric acid 4, iso-butyric acid 5.
Caproic acid 27	n-Caproic acid 25, iso-caproic acid 35.
Citronellol 16	d-Citronellol 22, l-citronellol 12.
Clove oil (75–90 percent eugenol) 19	Eugenol 70.
Geraniol 80	Geraniol 20.

Rate of Evaporation

The attractiveness of a bait was modified by changing its rate of evaporation. McIndoo (unpublished) and Metzger (unpublished) vaporized geraniol and eugenol rapidly in olfactometers and found that the strong odors of these chemicals were repellent to the beetles. Smith and Richmond (unpublished) used sweetened bran as a carrier to regulate the evaporation and to prolong the effectiveness of attractants in bait cans. The odor of a bran bait containing 10 percent of geraniol was initially repellent, but it became attractive as the geraniol was dissipated and the amount of the attractant in the air near the bait can decreased. Baits containing 2.5 and 5 percent of geraniol were immediately attractive.

In view of those results, a bran bait containing 2.5 percent of geraniol and 0.25 percent of eugenol was recommended initially for use in traps (Metzger *1928*). The bait, however, did not vaporize as rapidly in the trap as in the bait can. Van Leeuwen and Metzger (*1930*) found that the attractiveness of the trap was enhanced progressively as the amount of geraniol was increased to 10 percent and the amount of eugenol to 1 percent. This bran bait was most attractive immediately after placing it in the traps. It became progressively less attractive as the geraniol and eugenol evaporated. To maintain the effectiveness of the traps, Metzger (*1932*) recommended that the bait be replaced with fresh bait every 2 weeks.

The bottle-and-wick method for dispensing attractants, which was introduced by Metzger (*1933*), was superior to the bran bait, in that the evaporation rate of a pure compound remained practically constant as long as the wick was saturated with the liquid.

The evaporation rate was modified by increasing or decreasing the area of the wick exposed above the cap of the bait bottle. He found that by increasing the exposure of a ¼-inch ensheathed cotton wick from 1 to 2 and to 4 inches, the attractiveness of the 10:1 geraniol-eugenol mixture was enhanced by 20 and 40 percent, respectively. Fleming et al. (*1940a*) found that a ½-inch ensheathed cotton wick exposed 1¼ inches evaporated about the same amount of attractant as the ¼-inch wick exposed 2 inches. Fleming and Maines (unpublished) found that the attractiveness of a 9:1 anethole-eugenol mixture decreased progressively as the exposure of the ¼-inch wick was decreased from 1¼ to ¼ inch. The reduction in attractiveness was 9, 13, 16, and 26 percent with the wick exposed 1, ¾, ½, and ¼ inch, respectively.

Metzger (unpublished) found a direct relationship between the grams of the 10:1 geraniol-eugenol mixture evaporated from wicks during a 7-week period in the field and the attractiveness to the beetles. The attraction was enhanced 21, 28, and 31 percent when the evaporation was increased from 18 to 34, 40, and 48 grams, respectively.

Fleming et al. (unpublished), using ceramic and pumice blocks impregnated with a 20:2:1 mixture of geraniol, eugenol, and phenyl ethyl alcohol in competition with a ¼-inch cotton wick exposed 2 inches, found the relative attractiveness of the blocks as follows:

Grams per week of material evaporated	*Relative attractiveness (percent) of blocks*
0.25	40
.5	48
1	62
2	76
3	86
4	98
5	110
6	122
7	134

The general experience has been that usually 5 to 7 grams of the 10:1 geraniol-eugenol mixture and 26 to 30 grams of the 9:1 anethole-eugenol mixture evaporated from a ¼-inch cotton wick exposed 2 inches or from a ½-inch wick exposed 1¼ inches during 5 to 7 weeks in traps in the field. The evaporation rates of these mixtures were higher during hot periods and lower during cool weather. (Fleming et al. unpublished)

In a preliminary study of the evaporation of different chemicals from a ½-inch cotton wick in an insectary, Fleming et al. (unpublished) found that during a 6-week period the following amounts (grams) were evaporated: Eugenol 1.9, phenyl ethyl butyrate 2.5, caproic acid 6, and anethole 8. The evaporation of mixtures of these compounds approached that of their principal component. The small amounts evaporated and the variation in the replications of each chemical did not permit a critical evaluation.

Chisholm and Koblitsky (*1945*) increased the rate of evaporation by using a hollow cylindrical paper wick 75 mm. in circumference and 150 mm. high and reported the results in relative amounts as compared with eugenol, which was relatively constant in its evaporation rate during a 4-week period. Ten ml. of the compounds were introduced into the bait bottles.

During the first half week the relative evaporation rates as compared with eugenol with a value of 1.00 were deobase 6.71, anethole 3.95, geraniol 1.21, and mineral oil only 0.01. The 9:1 and 1:1 anethole-eugenol mixtures were 2.67 and 1.49, respectively, the 9:1 and 1:1 geraniol-eugenol mixtures 1.10 and 0.87, and the 9:1:5:5 mixture of geraniol, eugenol, deobase, and mineral oil 1.22. The evaporation rate of anethole, 9:1 anethole-eugenol, 1:1 anethole-eugenol, and 1:1 geraniol-eugenol remained fairly constant. All the anethole and the anethole-eugenol mixtures evaporated within 2½ weeks, but some of the 1:1 geraniol-eugenol remained at the end of 4 weeks.

On the other hand, during the eighth half week, the relative evaporation of geraniol decreased from 1.21 to 0.61, 9:1 geraniol-eugenol from 1.10 to 0.83, and 9:1:5:5 geraniol, eugenol, deobase, and mineral oil from 1.22 to 0.23. These substantial decreases in evaporation indicate a change in the composition of these baits during exposure. For best results the evaporation of a bait should remain constant during a period of 5 to 7 weeks in the field.

The baits that were relatively constant in their evaporation rates—eugenol, the 19:1 and 9:1 mixtures of anethole and eugenol, and the 5:1, 5:2, 5:4, and 1:1 mixtures of geraniol and eugenol—did not change substantially in their attractiveness during a 6-week period in the field. However, geraniol and the 10:1 mixture of geraniol and eugenol lost 39 and 23 percent, respectively, of their attractiveness during this period. (Fleming and Maines unpublished; Fleming et al. unpublished)

Decomposition of Attractants

There was a change in the color of technical geraniol, technical caproic acid, U.S.P. eugenol, and mixtures of these chemicals exposed in green glass bottles in traps in the field. Sometimes a gummy deposit accumulated on the wicks. Geraniol became dark yellow to brown, caproic acid red, eugenol brown, and mixtures of geraniol with caproic acid or eugenol dark brown to black. Decomposition of the anethole-eugenol mixtures was not indicated.

Decomposition in Bait Bottle.—Chisholm et al. (unpublished) and Fleming et al. (unpublished) determined the change in the color density, refractive index, and relative viscosity of several baits in the bait bottle during an exposure of 5 to 6 weeks in green glass bottles in survey traps in the field. The color density is defined as the negative logarithm of the fractional transmission of light through a liquid. It has a value of 1 when 10 percent of the incident light is transmitted and a value of 0 when all the light is transmitted. In this bulletin the color density is expressed as the percent increase in the light absorbed by a bait after exposure.

There was little change in the composition of C.P. geraniol during exposure, as indicated by an increase of about 1 percent in the light absorbed, but the composition of some of the technical geraniols changed considerably. The increase in the light absorbed by the technical geraniols ranged from 2 to 49 percent. The technical geraniols affected least by weathering contained no phenols. When the technical geraniols were washed with 5 percent aqueous potassium hydroxide to remove the phenols before exposure, the change in the composition was reduced considerably. Some of the washed geraniols showed no increase in the absorption of light; the maximum increase was 13 percent. There was little increase in the absorption of light by some of the pure constituents of technical geraniol—d-citronellol, d-citronellyl acetate, citronella terpenes, citronellal, elemol, gamma cadinene, and geranyl acetate. The greatest increase in the refractive index occurred with the citronella terpenes and citronellal, and the greatest increase in the relative viscosity with elemol, citronellal, gamma cadinene, and the citronella terpenes, but all these increases were small. The change in the physical properties of technical geraniol appeared to be dependent on the amounts of other compounds, particularly phenols, in the commercial product.

Eugenol was readily decomposed on exposure to light. The average increase in the light absorbed was 85 percent, in the refractive index 0.0029, and in the relative viscosity 0.43.

The change in the physical properties of mixtures of C.P. geraniol and C.P. eugenol increased with the increment in the amount of eugenol in the mixtures. The increase in the amount of light absorbed ranged from 56 percent with the 9:1 mixture to 86 percent with the 1:9 mixture, the increase in the refractive index of these mixtures was from 0.0008 to 0.0036 and the increase in the relative viscosity was from 0.13 to 0.35. Similar results were obtained with mixtures of technical geraniol and U.S.P. eugenol.

Changes in the absorption of light by mixtures of C.P. eugenol and other chemicals differed greatly. After weathering, the absorption was decreased 55, 36, and 23 percent with perilla oil, rose geranium oil, and palmarosa oil, respectively. The percent increase was as follows: d-Citronellol, l-citronellol, and geranyl acetate 1; phenyl ethyl acetate 5; butyl carbitol acetate 14; anethole 18; amyl salicylate and methyl salicylate 20; citral 37; alpha terpineol 63; benzyl ether 69; acetophenone 83, and methyl anthranilate 100.

Decomposition in Wick.—Chisholm and Koblitsky (*1945*) studied the changes in the composition of baits in paper wicks during evaporation of 70 to 80 percent of the liquids. The changes in the wicks were similar to those in the bait bottles. As indicated by the refractive indices, anethole did not change during evaporation. There was slight decomposition of the 9:1 and 1:1 mixtures of anethole and eugenol. The composition of technical geraniol, eugenol, and the 9:1 and 1:1 mixtures of these components changed substantially. If the evaporation had been continued, the liquids in the wicks probably would have consisted largely of the decomposition products and the less volatile constituents of the baits.

Retarding Decomposition of Bait.—In a preliminary laboratory experiment Chisholm (unpublished) exposed technical geraniol and mixtures of geraniol with acids and mineral oil for 18 hours to a mercury vapor arc and determined the modification in the color of the liquids. One gram of the potential retarding agent was mixed with 100 ml. of geraniol. After exposure, the color density of geraniol was such that 55 percent of the light was absorbed. By adding various materials, the percent of light absorbed was as follows: Oleic acid 52, glacial acetic acid 51, mineral oil 50, phthalic anhydride 45, benzoic acid 43, palmitic acid 35, lactic acid 20, and citric acid 13.

In field tests Chisholm et al. (unpublished) found that after a 4-week exposure the 10:1 technical geraniol-U.S.P. eugenol mixture had so increased in color density that the absorption of light was increased by 55 percent. When substituted for eugenol in the mixture, thymol, clove oil, and safrole increased the absorption by 31, 48, and 84 percent, respectively. On the other hand, there was practically no decomposition of a 50:1 mixture of the geraniol with citric acid or lactic acid. Fleming et al. (unpublished) found that the 9:1 mixtures of C.P. geraniol with acetophenone, amyl salicylate, anethole, butyl carbitol, citral, methyl salicylate, and alpha terpineol were substantially unchanged by exposure in the field. Geraniol-methyl anthranilate was definitely decomposed as indicated by a 97-percent increase in the light absorbed.

Another approach to reducing the decomposition of the technical geraniol-U.S.P. eugenol mixture in the survey trap was to shield the green glass bottle from light. The wick was protected from the weather by being covered with an inverted metal cone. The bottle and wick in the standard trap were protected from the weather by being enclosed in a perforated metal cylinder. Chisholm et al. (unpublished) and Fleming et al. (unpublished) found that the absorption of light by the 10:1 mixture exposed for 6 weeks in the glass bottle in the survey trap was increased by 67 percent. The increase in light absorption was reduced to about 30 percent by painting the outside of the glass bottle green or white or by enclosing the bottle in a solid metal shield.

Effect of Decomposition of Bait on Its Attractiveness.—The decomposition of eugenol in green glass bottles in the field did not change its attractiveness during a 5- or 6-week period, indicating that the products of decomposition did not change its effectiveness. Mixtures of geraniol and eugenol decomposed, but their attractiveness was not changed substantially. The dark decomposition products of eugenol seemed to stabilize the attractiveness of the mixtures. (Fleming et al. unpublished)

Although several compounds substituted for eugenol practically prevented the decomposition of technical geraniol, most of the mixtures were much less attractive than the 10:1 geraniol-eugenol mixture. Their relative attractiveness (percent) was as follows: 9:1 geraniol-acetophenone 32, 9:1 geraniol-amyl salicylate 49, 9:1 geraniol-anethole 29, 9:1 geraniol-citral 51, 50:1 geraniol-citric acid 50, and 50:1 geraniol-lactic acid 56. Only three mixtures approached the geraniol-eugenol mixture in attractiveness. The relative attractiveness (percent) of 9:1 geraniol-methyl salicylate was 86, 9:1 geraniol-butyl carbitol acetate 96, and 9:1 geraniol-alpha terpineol 99. (Fleming et al. unpublished)

Painting the outside of the green glass bottle or enclosing the bottle in a solid metal shield to protect it from sunlight was the most practical method for inhibiting the decomposition of the 10:1 geraniol-eugenol mixture in the survey trap. During a 6-week exposure the relative attractiveness of the bait in an exposed green glass bottle was 97 percent. It was 127 and 136 percent, respectively, in a bottle painted white or green and 135 percent with the bottle enclosed by a solid metal shield painted white or yellow. (Fleming et al. unpublished)

Mixtures of Compounds

Mixtures of chemicals were almost invariably more attractive to the beetle than would be expected from the attractiveness of their components. For example, when bay oil with a relative attractiveness of 19 percent was mixed 1:1 with pimenta oil with a relative attractiveness of 54 percent, the relative attractiveness of the mixture would be expected to be about 37 percent. The mixture was determined to have a relative attractiveness of 44 percent. The same situation prevailed with other binary mixtures of oils, oils mixed with acids, alcohols, or phenols, acids mixed with phenols, alcohols mixed with other alcohols, acids, aldehydes, esters, or phenols, aldehydes mixed with phenols, esters mixed with phenols, and mixtures of phenols. The difference between the expected and determined attractiveness of some mixtures was small, but it was large with others, as shown in the following list:

Components of mixture	*Relative attractiveness (percent)* Determined	*Relative attractiveness (percent)* Expected
Oil mixed with oil		
Bay oil + pimenta oil 1:1	44	37
Bay oil + sassafras oil 1:1	31	19
Pimenta oil + sassafras oil 1:1	57	37

Components of mixture	*Relative attractiveness (percent)* *Determined*	*Expected*
Oil mixed with acid		
Bay oil + valeric acid 1:9	75	28
Linaloe oil + valeric acid 1:1	55	19
Pimenta oil + caproic acid 1:1	72	41
Pimenta oil + propionic acid 1:4	43	37
Pimenta oil + valeric acid 1:9	68	32
Sassafras oil + caproic acid 1:1	49	23
Sassafras oil + valeric acid 1:9	69	28
Oil mixed with alcohol		
Bay oil + phenyl ethyl alcohol 1:9	64	23
Clove oil + geraniol 1:9	82	74
Clove oil + phenyl ethyl alcohol 1:9	50	23
Pimenta oil + geraniol 1:9	103	77
Pimenta oil + phenyl ethyl alcohol 1:9	48	26
Oil mixed with phenol		
Anise oil + eugenol 9:1	19	10
Citronella oil + eugenol 10:1	121	76
Clove oil + anethole 1:9	53	16
Grapefruit oil + eugenol 9:1	84	13
Lemon oil + eugenol 9:1	37	13
Pimenta oil + eugenol 9:1	95	56
Pine oil + eugenol 9:1	17	9
Sassafras oil + eugenol 9:1	51	24
Acid mixed with phenol		
Caproic acid + anethole 1:1	58	22
Caproic acid + eugenol 9:1	61	31
Alcohol mixed with alcohol		
Geraniol + phenyl ethyl alcohol 10:1	98	74
Alcohol mixed with acid		
Geraniol + caproic acid 1:4	103	38
Alcohol mixed with aldehyde		
Geraniol + benzaldehyde 199:1	66	40
Geraniol + citral 1:9	57	26
Alcohol mixed with ester		
Geraniol + methyl salicylate 9:1	86	73
Geraniol + phenyl ethyl acetate 1:4	84	20
Alcohol mixed with phenol		
Citronellol + eugenol 10:1	90	21
Geraniol + anethole 1:9	51	22
Geraniol + eugenol 9:1	100	79
Geraniol + safrole 10:1	40	73
Phenyl ethyl alcohol + eugenol 9:1	74	28
Aldehyde mixed with phenol		
Citral + eugenol 9:1	71	25
Citronellal + eugenol 10:1	45	19

Components of mixture	*Relative attractiveness (percent)* *Determined*	*Expected*
Ester mixed with phenol		
iso-Amyl valerate + eugenol 9:1	53	11
Geranyl acetate + eugenol 10:1	75	39
Methyl salicylate + eugenol 9:1	20	14
Phenyl ethyl acetate + eugenol 1:9	99	64
Phenol mixed with phenol		
Anethole + eugenol 9:1	101	22
Safrole + eugenol 9:1	32	12

The proportion of the components of a mixture is also a factor modifying the attractiveness. The relative attractiveness of the 9:1 and 1:1 mixtures of anethole and caproic acid was 12 and 58 percent, respectively. The relative attractiveness of anethole-eugenol mixtures decreased progressively from 113 with the 19:1 mixture to 83 percent with the 2:3 mixture, whereas the attractiveness of geraniol-eugenol mixtures increased from 98 with the 10:1 mixture to 165 percent with the 5:4 mixture. The relative attractiveness, respectively, of the 8:1:1, 1:1:8, and 1:2:8 mixtures of geraniol, eugenol, and phenyl ethyl acetate was 130, 108, and 72 percent; the 20:2:1 and 10:1:2 mixtures of geraniol, eugenol, and phenyl ethyl alcohol 123 and 106 percent; the 8:1:1, 1:1:1, and 1:1:8 mixtures of geraniol, eugenol, and phenyl ethyl butyrate 144, 195, and 222 percent; the 2:2:1, 3:6:1, 6:3:1, and 9:9:2 mixtures of anethole, caproic acid, and eugenol 133, 176, 202, and 246 percent.

Technical Geraniol

Source and Composition

Pure geraniol is an unsaturated aliphatic alcohol with the empirical formula $C_{10}H_{17}OH$. It is a colorless liquid with a molecular weight of 154.25, a refractive index of 1.4798, a density (gram per milliliter) of 0.8812, a melting point less than —15° C., and a boiling point of 229° at 760 mm. Fleming et al. (unpublished) found it was only about 25 percent as attractive as most technical geraniols of commerce.

Technical geraniol is usually obtained by the fractional distillation of Java citronella oil, although Ceylon citronella oil or palmarosa oil may be used. It is a complex mixture. Metzger and Maines (*1935*) found that the best commercial grades contained 87 percent or more of geraniol and citronellol, no aldehydes, and a trace of esters; the intermediate grades contained 80 to 86 percent of geraniol and citronellol, 0 to 1.2 percent of citronellal, and 0.9 to 1.3 percent of esters; and the poor grades contained 50 to 75 percent of geraniol and citronellol, 1 to 10 percent of citronellal, and 2 to 20 percent of esters.

Jones and Haller (*1941*) isolated and purified the constituents of a technical geraniol and found its approximate composition was as follows:

Component	*Percent*
Geraniol	34
Nerol (isomer of geraniol not reacting with calcium chloride)	7
d-Citronellol	17
Elemol	10
gamma Cadinene	8
Geranyl acetate	8
gamma Cadinol and other sesquiterpene alcohols	7
Terpenes (probably limonene and dipentene)	4
d-Citronyl acetate	2
Eugenol	1
Aldehydes (probably citronellal)	1
iso-Eugenol	.2
Geranyl butyrate	.2

Fleming et al. (unpublished) subjected a technical geraniol to fractional steam distillation and compared the fractions with those of the original geraniol. The first fraction, which was 75 percent of the original volume, contained all the terpenes and aldehydes, most of the citronellol and geraniol, and much of the esters. It attracted 20 percent more beetles than the original geraniol. The second fraction, which was 15 percent of the original volume, consisted primarily of eugenol, gamma cadinene, elemol, and some geraniol. It attracted 34 percent more beetles than the original geraniol. The third fraction, which was 10 percent of the original volume, contained gamma cadinene, elemol, the higher sesquiterpene alcohols, and some eugenol. It attracted about the same number of beetles as the original geraniol. The results indicated that the most attractive components of the geraniol were in the first and second fractions.

Chisholm et al. (unpublished) by chemical treatment of technical geraniol obtained a fraction that was practically pure geraniol, another fraction containing a small amount of geraniol and other alcohols, principally citronellol, and a third fraction containing the natural esters with some alcohols and other compounds. In the treatment, the acids, some of the aldehydes, and the pheonls were lost. Fleming et al. (unpublished) found the first fraction attracted 31, second 18, and third 4 percent as many beetles as the original geraniol.

Fleming et al. (unpublished) determined the attractiveness of the components of the technical geraniol that had been isolated and purified by Jones and Haller (*1941*). In comparison with the original geraniol, the relative attractiveness (percent) of the components was as follows: Eugenol 80, sesquiterpene alcohols 59, d-citronellol 26, elemol 24, geraniol 18, gamma cadinene 13, geranyl acetate 11, citronellyl acetate 9, citronellal 8, and terpenes 5. Eugenol was by far the most attractive component, indicating that the attractiveness of technical geraniol is affected more by the amount of eugenol in the mixture than by the other components. Geraniol was not the primary attractant for the beetle as claimed by Richmond (*1927*), who tested only the technical product.

Specifications for Technical Geraniol

No standards for technical geraniol are in the U.S. Pharmacopoeia or the National Formulary. It is used chiefly as a perfume. The discovery of its attractiveness to the beetle offered a new outlet for the product. As a perfume the odor of the product was the principal criterion. Such commercial designations as "pure," "absolute," "extra," and "prime" by the various producers identified the products with a high content of alcohol used in perfume to distinguish them from the cheaper less desirable products used in soap. No specifications were given for technical geraniol as an attractant for insects.

To develop a tentative specification for technical geraniol, Metzger (unpublished) in 1927 tested the attractiveness of 13 lots of the product with a total alcoholic content ranging from 37 to 93 percent. There seemed to be no close relationship between the amount of alcohol in a product and its attractiveness. Some lots low in alcohol were among the most attractive. The more attractive lots contained at least 58 percent total alcohol. Since at that time the amount of alcohol in the product was considered to be most important, Metzger (*1928*) and Van Leeuwen and Metzger (*1930*) recommended that the technical geraniol for use as an attractant contain not less than 58 percent total alcohol.

The technical geraniols obtained with that specification differed widely in their attractiveness, a situation attributed to the great range in the amount of total alcohol permitted. A highly refined grade of technical geraniol seemed to be required to overcome that situation. Vander Meulen (unpublished) prepared the following specifications for a highly refined grade of technical geraniol:

Total alcohols as geraniol	Not less than 87 percent
Aldehydes	None
Specific gravity at 20° C	0.879–0.882
Optical rotation, 10 mm	± 0° 30′
Solubility in 60 percent ethyl alcohol	1 part in 4 parts of alcohol

The lots of technical geraniol obtained from a few producers were fairly consistent in their attractiveness. In 1933 the quantity of technical geraniol required by governmental agencies was so large that many producers competed for the contracts. Some lots were offered at a price much below any previous quotation, but these failed to meet one or more of the specification requirements. One lot had been adjusted by the adding of other products to satisfy these requirements, but it was rejected because of its uncharacteristic odor, even though odor was not part of the specifications. (Metzger unpublished; Metzger and Maines *1935*)

After consultations with the major producers of technical geraniol in the spring of 1933, Metzger (unpublished) proposed the following specifications to define more precisely the characteristics of a highly refined grade of geraniol:

Total alcohols as geraniol	Not less than 87 percent
Aldehydes	None
Specific gravity at 20° C.	0.876–0.882
Optical rotation, 10 mm.	Less than ± 0° 30′
Solubility in 60 percent ethyl alcohol	1 part in 3 parts of alcohol
Boiling range (760 mm.)	None distilling below 224° C. and not less than 82 percent between 225° and 230°
Odor	Characteristic of high grade of geraniol

Since geraniols with less alcohol than the minimum required by the 1933 specifications were much cheaper than the highly refined grade, the question was raised whether the highly refined grade was necessary for use as an attractant. To study this matter further, Metzger and Maines (*1935*) obtained 22 lots of technical geraniol in the best, intermediate, and poor grades from several producers and determined their physical properties, the amounts of citronellol, geraniol, citronellal, and the esters in them, and their attractiveness to the beetle. Some of the lots in the intermediate and poor grades were more attractive than those in the highly refined grade, showing that the best grade was not essential for use as an attractant. Esters seemed to enhance the attractiveness. Aldehydes in limited quantities did not seem to inhibit the attractiveness.

As a result of this investigation, Metzger and Maines (*1935*) proposed the following specifications for some of the less costly technical geraniols:

Total free alcohols as geraniol and citronellol	More than 70 percent
Aldehydes as citronellal	Less than 3.5 percent
Esters as geranyl acetate	Less than 15 percent
Specific gravity at 20° C.	0.875–0.895
Solubility in 70 percent ethyl alcohol	1 part in 2 parts of alcohol
Boiling range (760 mm.)	Not more than 5 percent below 225° C. nor more than 18 percent above 245°
Odor	Absence of any significant added foreign material

In 1935 a technical geraniol meeting these specifications could be obtained for about 60 cents per pound, whereas one satisfying the 1933 specifications cost about $1.50 per pound.

The boiling range claimed by a producer for a lot of technical geraniol was not always confirmed at the Japanese Beetle Laboratory. The producers used different methods and apparatus for their determinations, and the results were affected by the type of distillation apparatus, the rapidity of distillation, the barometric pressure, and other factors. Koblitsky and Chisholm (*1940*) developed a standardized procedure for determining the boiling range. With this procedure duplicate determinations differed by less than 1° C. The procedure was adopted as the official method.

The physical properties and the chemical composition of the technical geraniols submitted by producers in response to invitations for quotations were determined to ascertain whether they complied with the 1935 specifications, and during the summer their attractiveness was evaluated. In 1935 Metzger (unpublished) found that four of the five lots of geraniol submitted met the requirements of the specifications; the fifth lot was too low in total alcohol and too high in aldehydes. The four lots meeting the specifications attracted about the same number of beetles as the highly refined product, but the other one attracted 23 percent fewer beetles. In 1936 Metzger (unpublished) tested three lots submitted and found that they attracted 2 to 14 percent more beetles than the highly refined product. In 1938 Fleming et al. (unpublished) found that two lots of geraniol meeting the specifications differed greatly in their attractiveness. The cheaper one attracted 1.4 times as many beetles as the other.

In 1939 two lots of geraniol meeting the 1935 specifications were analyzed and tested in competition with the standard geraniol-eugenol mixture. The relative attractiveness of the one, which contained only a few components, was 77 percent, whereas the other, containing many components differing widely in their physical properties, had a relative attractiveness of 125 percent. (Chisholm et al. unpublished; Fleming et al. unpublished; Jones and Haller *1940*)

In 1940 only one of six lots of geraniol submitted met the specifications. Its relative attractiveness was 76 percent. The first lot rejected contained 29.1 percent aldehydes and 55 percent of it distilled below 225° C. Its relative attractiveness was only 35 percent. The second lot rejected had only 0.6 percent more esters than the maximum specified and it contained a trace of phenols. Its relative attractiveness was 74 percent. The third lot rejected had 4 percent more than the maximum specified, distilling above 245°. It contained 2.5 percent phenols and its relative attractiveness was 83 percent. The fourth lot rejected had a specific gravity 0.0137 higher than the maximum specified, and 24 percent more than the specified maximum distilled above 245°. It contained 25.8 percent esters, 66.4 percent alcohols, and 6 percent phenols. Its relative attractiveness was 89 percent. The fifth lot rejected had a specific gravity 0.0332 higher than the maximum specified and 98 percent of it distilled above 245°. It contained 54 percent alcohols and 5 percent phenols. Its relative attractiveness was only 43 percent. The same situation prevailed in 1941. (Fleming et al. unpublished)

The 1935 specifications were inadequate in that lots of technical geraniol meeting these requirements differed widely in their attractiveness, and some lots with less alcohols, more esters, and eugenol were at least as attractive. This situation showed that a further investigation should be made to define more precisely the physical and chemical properties of an attractive technical geraniol. Jones and Haller (*1940*) suggested that to obtain a more definite product, consideration also should be given to the determination of the viscosity and optical rotation, as well as chemical determinations sufficient to establish the composition of the product. In view of the deteriorating economic conditions in 1941 this investigation was not undertaken.

In 1942 it was not possible for the Department to purchase at a reasonable cost a sufficient quantity of technical geraniol meeting the 1935 specifications. Fleming et al. (unpublished) developed temporary emergency specifications, which included some of the higher boiling fractions of citronella oil that were available at a reasonable cost. The lots obtained in 1942 and 1943 compared favorably in attractiveness with those obtained previously with the 1935 specifications, but in 1944 the technical geraniols available did not meet even those broad specifications and most of them were poor attractants. It was necessary at that time to discontinue the use of technical geraniol as a component of the bait.

Mixtures of Technical Geraniol and Eugenol

In 1925 and 1926, Richmond (*1927*) and Smith and Richmond (unpublished) found that a bran bait containing 2.5 percent technical geraniol and 0.25 percent U.S.P. eugenol was more attractive to the beetle than either chemical alone. Fleming et al. (unpublished) found that when tested in competition with a 10:1 technical geraniol-U.S.P. eugenol mixture, the technical geraniol on the average had a relative attractiveness of 80 percent and C.P. geraniol 20 percent, but the 10:1 mixtures of these geraniols and eugenol were equivalent in attractiveness.

Metzger (*1928*) and Richmond and Metzger (*1929*) recommended 150 grams of a mixture with the following composition for baiting the standard trap:

Geraniol (technical)	3.75 grams.
Eugenol (U.S.P.)	.375 gram.
Bran	75 grams.
Molasses	39 ml.
Glycerin	6 ml.
Water	13 ml.

The molasses, glycerin, and water were added to keep the bait moist and to hold the ingredients together. A bait was usually effective for about 3 weeks. Since the traps were operated for not more than 6 or 8 weeks, one or two changes of the bait during the summer were usually sufficient.

Van Leeuwen and Metzger (*1930*) tested various amounts and proportions of technical geraniol and U.S.P. eugenol in the bran bait in competition with the recommended bait and found that the attractiveness was enhanced 160 percent by increasing the amount of geraniol to 15 grams and the amount of eugenol to 1.5 grams. This modified bran bait was recommended for several years (Van Leeuwen and Metzger *1930*; Metzger *1932, 1934a, 1936*; Fleming et al. *1940a*).

One disadvantage of the bran bait was that its attractiveness decreased progressively as the geraniol and the eugenol evaporated. Searching for a method to dispense the bait more uniformly throughout the trapping season, Metzger (*1933*) placed the 10:1 geraniol-eugenol mixture in a glass bottle and dispensed it by means of a cotton wick. The beetles were attracted until the attractant was exhausted. The rate of evaporation was modified by the exposure of the wick. A 1/4-inch cotton wick exposed 2 and 4 inches attracted 7 and 27 percent, respectively, more beetles than the bran bait during an 8-day exposure.

The use of the bottle-and-wick dispenser was an important development. Not only could sufficient bait be placed in the bottle to last 5 to 7 weeks but it could be discerned readily when practically all the bait had evaporated. After 1933 the bottle-and-wick dispenser was used by the Department in the survey program and in experimental work. The 10:1 geraniol-eugenol liquid bait was recommended in preference to the bran bait by Metzger (*1934a, 1936*) and by Fleming et al. (*1940a*).

Fleming and Burgess (*1940*) and Fleming et al. (unpublished) found that the attractiveness of the liquid bait was enhanced by increasing the amount of eugenol in the mixture. During a 6-week exposure in the field when the standard geraniol-eugenol mixture was changed weekly, the relative attractiveness of the 10:1 mixture exposed for that period was 98 percent, whereas the 5:1, 5:2, 5:4, and 1:1 mixtures were 142, 146, 165, and 153 percent, respectively.

In 1939 technical geraniol was obtained in large quantities for 32.4 cents per pound, whereas U.S.P. eugenol cost $1.12 per pound. The substitution of the 5:1 mixture for the 10:1 mixture would have increased the cost of the bait about 15 percent. Since the Department at that time was purchasing about 4,000 pounds of bait annually, an increase of 15 percent in the cost was not considered feasible. By 1944 when the cost of technical geraniol and U.S.P. eugenol was about the same, it would have been practical to increase the amount of eugenol in the mixture, but at that time little geraniol was available.

Consideration was given to reducing the cost of the geraniol-eugenol mixture by diluting it with an inert substance. Fleming et al. (unpublished) used ethylene glycol and dimethylphthalate as diluents. Ethylene glycol was not satisfactory because it absorbed moisture from the atmosphere, and the geraniol-eugenol-ethylene glycol mixtures soon separated into two layers with most of the geraniol and eugenol in the upper layer. The geraniol-eugenol-dimethylphthalate mixtures remained homogeneous in the field, but the attractiveness progressively decreased with the increment in the amount of dimethylphthalate. The relative attractiveness of the 9:1 geraniol-eugenol mixture was reduced from 100 to 87, 83, and 74 percent by a 3:1, 2:1, and 1:1 dilution, respectively.

Muma et al. (*1944*) were more successful with a 1:1 mixture of mineral oil and deobase oil as a diluent. The relative attractiveness of the 9:1 geraniol-eugenol mixture did not change appreciably until the dilution of the bait was more than 1:1. The relative attractiveness was reduced from 100 to 90, 63, 56, and 48 percent by a 2:3, 3:7, 1:4, and 1:9 dilution, respectively. In more extensive tests Muma et al. (*1945*) found that the 9:1 bait diluted with an equal volume of the oils was 98 percent as effective as the undiluted bait. The bait diluted 7:3 and 1:1 was used extensively in Maryland during 1944 with very satisfactory results. A more attractive but more costly bait was obtained by diluting the 1:1 mixture of geraniol and eugenol 7:3 with the oils. The relative attractiveness of the 1:1 mixture was reduced from 153 to 140 percent by that dilution.

Several substances were added to the technical geraniol-U.S.P. eugenol mixtures to enhance their attractiveness. Some of these substances decreased the attractiveness or had little effect on it. The addition of caproic acid, phenyl ethyl acetate, phenyl ethyl alcohol, phenyl ethyl butyrate, and phenyl iso-valerate in certain proportions definitely increased the attractiveness, as indicated in the following data:

Composition of bait by volume and relative attractiveness (percent)[1]	*Source*
Geraniol + eugenol + caproic acid 1:1:8 (173)	Langford and Cory *1946*.
Geraniol + eugenol + caproic acid + phenyl ethyl butyrate 1:1:12:1 (178), 4:1:4:1 (232)	Do.
Geraniol + eugenol + phenyl ethyl acetate 8:1:1 (130)	Langford and Gilbert *1949*.
Geraniol + eugenol + phenyl ethyl alcohol 20:2:1 (123), 10:1:1 (129)	Metzger *1936*, unpub.
Geraniol + eugenol + phenyl ethyl butyrate 8:1:1 (144), 1:1:1 (195), 1:1:8 (222)	Langford and Cory *1946*.
Geraniol + eugenol + phenyl iso-valerate 1:1:8 (378)	Do.

[1] Parenthetical numbers in percent.

The exploratory tests showed that the attractiveness of the geraniol-eugenol bait could be greatly increased by adding caproic acid, phenyl ethyl butyrate, or phenyl iso-valerate, but there was no additional experimentation with these mixtures. Only the

20:2:1 mixture of geraniol, eugenol, and phenyl ethyl alcohol was tested more extensively. Metzger (*1935*) recommended this mixture as an attractant. This bait was used in the survey program of the Department during 1936–39. Since the highly refined geraniol used in the experiments had been replaced by the lower grades meeting the 1935 specifications, Fleming et al. (unpublished) tested the 20:2:1 mixture prepared with these geraniols and found that the relative attractiveness of the mixtures ranged from 73 to 172 percent, depending on the composition of the technical geraniols. In view of this situation the use of phenyl ethyl alcohol in the bait was discontinued in 1939.

Mixtures of Technical Geraniol Not Containing Eugenol

Several compounds were added to technical geraniol as a substitute for U.S.P. eugenol. Fleming et al. (unpublished) found that the binary mixtures prepared with geraniol and acetic acid, acetophenone, amyl salicylate, anethole, bay oil, benzaldehyde, citral, citric acid, citronellol, geranyl acetate, lactic acid, methyl anthranilate, safrole, thymol, triethanolamine, or vanillin attracted less than 76 percent as many beetles as the geraniol-eugenol standard.

Some mixtures approached the geraniol-eugenol standard in attractiveness. They were as follows:

Composition of bait by volume and relative attractiveness (percent)[1]	*Source*
Geraniol + butyl carbitol acetate 9:1 (96)	Fleming et al. unpub.
Geraniol + caproic acid 4:1 (103)	Langford and Cory *1946*.
Geraniol + clove oil 10:1 (98), 9:1 (82)	Fleming et al. unpub.
Geraniol + methyl salicylate 9:1 (86)	Do.
Geraniol + phenyl ethyl acetate 1:4 (84)	Langford and Gilbert *1949*.
Geraniol + phenyl ethyl alcohol 20:1 (90), 10:1 (98), 5:1 (84)	Metzger *1935*, unpub.; Fleming et al. unpub.
Geraniol + pimenta oil 9:1 (103)	Fleming and Chisholm *1944*; Fleming et al. unpub.
Geraniol + alpha terpineol 9:1 (99)	Fleming et al. unpub.

[1] Parenthetical numbers in percent.

Langford and Cory (*1946*) found that the 2:9:9 mixture of geraniol, anethole, and caproic acid had a relative attractiveness of 182 percent.

Commercial Citronella Oil

Source and Composition

According to Gildmeister and Hoffman (*1916*), commercial citronella oil is obtained by steam distillation of citronella grass (*Cymbopogon nardus* (L.) Rendle). The principal sources are

Ceylon and Java. The Ceylon oil is a yellowish to brownish yellow liquid with a characteristic odor. The Java oil is colorless to slightly yellowish with a more intense odor than the Ceylon oil. The oil from both sources is a complex mixture of hydrocarbons, alcohols, esters, phenols, and other compounds.

Metzger (unpublished) analyzed nine lots of each type of oil. The Ceylon oil contained 36 to 47 percent alcohols, 8 to 11 percent esters, and 9 to 13 percent aldehydes. The Java oil contained 55 to 70 percent alcohols, 3 to 7 percent esters, and 26 to 39 percent aldehydes. The total acetylizable constituents after the aldehydes had been removed ranged from 46 to 57 percent with the Ceylon oil and from 60 to 74 percent with the Java oil. Eighty-five percent of the Ceylon oils distilled between 190° and 256° C. at 760 mm. and the Java oils between 210° and 248°.

Arrangements were made with a commercial producer to distill Java citronella oil under high vacuum according to the regular procedure. The oil had a refraction index of 1.4685 at 25° C., a specific gravity of 0.8873 at 20°, and 82 percent distilled between 208.4° and 242.1° at 760 mm. The first fraction was largely water and was discarded. The terpene fraction, which was largely terpenes, had a refraction index of 1.4624, a specific gravity of 0.8500, and 82 percent distilled between 169.9° and 198.4°. The citronellal fraction, which contained 79.3 percent aldehyde, had a refraction index of 1.4516, a specific gravity of 0.8693, and 82 percent distilled between 193.9° and 212.8°.

The first geraniol fraction, which contained 9.7 percent esters, 29.1 percent aldehydes, and 87.1 percent alcohols had a refraction index of 1.4656, a specific gravity of 0.8805, and 82 percent distilled between 209.9° and 231.4° C. It should be noted that the values for alcohols include aldehydes and free and combined alchols expressed as geraniol. The second geraniol fraction, which contained 15.6 percent esters, 1.7 percent aldehydes, 94.0 percent alcohols, and a trace of phenol, had a refraction index of 1.4689, a specific gravity of 0.8810, and 82 percent distilled between 227.0° and 234.9°. The third geraniol fraction, which contained 25.8 percent esters, 1.0 percent aldehydes, 66.4 percent alcohols, and 6.0 percent phenols, had a refraction index of 1.4810, a specific gravity of 0.9087, and 82 percent distilled between 233.9° and 256.3°. The last geraniol fraction, which contained 13.7 percent esters, 1.1 percent aldehydes, 54.2 percent alcohols, and 5.0 percent phenols, had a refraction index of 1.4914, a specific gravity of 0.9282, and 50 percent distilled between 243.7° and 267.5°, the limit of the thermometer. The pots fraction, which was not analyzed, had a refraction index of 1.4978 and a specific gravity of 0.9436. (Fleming et al. unpublished)

The second geraniol fraction met the 1935 specifications for technical geraniol, except that the esters were 0.6 percent higher than the maximum specified. The third geraniol fraction was typical of the technical geraniol obtained with the emergency specifications of 1942.

Java citronella oil and its fractions obtained by distillation decomposed during a 6-week exposure in the field, as indicated by the increase in the color density, the refraction index, and the relative viscosity. The absorption of light increased (percent) as follows: Oil 18, terpene fraction 4, citronellal fraction 7, first geraniol fraction 1, second geraniol fraction 11, third geraniol fraction 30, last geraniol fraction 24, and pots fraction 100. The increase in the refraction index was 0.0045, 0.0132, 0.0094, 0.0024, 0.0011, 0.0020, 0.0006, and 0.004, respectively, and the increase in the relative viscosity was 0.66, 0.84, 0.96, 0.54, 0.13, 0.18, 1.97, and 42.80, respectively. (Fleming et al. unpublished)

In comparison with the geraniol-eugenol standard, the relative attractiveness (percent) of Java citronella oil was 77, terpene fraction 4, citronellal fraction 16, first geraniol fraction 35, second geraniol fraction 74, third geraniol fraction 89, last geraniol fraction 65, and pots fraction 13 (Fleming et al. unpublished). Langford et al. (*1943*) apparently tested a poor grade of citronella oil because they reported a relative attractiveness of only 26 percent.

Mixtures of Citronella Oil and Eugenol

The addition of U.S.P. eugenol greatly enhanced the attractiveness of citronella oil. The relative attractiveness of 10:1 mixtures of the oil and U.S.P. eugenol, prepared with nine lots of the Ceylon oil, ranged from 114 to 129 percent and with 12 lots of the Java oil from 108 to 139 percent. The average relative attractiveness of the mixtures with the Ceylon oil or the Java oil was 121 percent. There was no indication that the attractiveness of these mixtures changed substantially during a 6-week exposure in the field. (Metzger unpublished)

Tashiro and Fleming (*1954*) found that adding U.S.P. eugenol to Java citronella oil increased its attractiveness to the European chafer (*Amphimallon majalis* (Razoumousky)). The increase in attractiveness (percent) with the 9:1 mixture was 3, 7:3 mixture 29, 4:1 mixture 9, and 3:1 mixture 20.

The addition of phenyl ethyl alcohol to the 10:1 citronella oil-eugenol mixture did not modify its attractiveness. The relative attractiveness of the 20:2:1 mixture of citronella oil, eugenol, and phenyl ethyl alcohol was 114 percent. (Metzger unpublished)

Replacing eugenol with clove oil greatly reduced the attractiveness. The relative attractiveness of the 18:1:1 mixture of citronella oil, clove oil, and phenyl ethyl alcohol was only 69 percent. (Langford and Cory *1946*)

A 10:1 mixture of Java citronella oil and U.S.P. eugenol was a promising substitute for the recommended geraniol-eugenol bait. It was slightly more attractive to the beetle and the oil could be obtained for about one-half the cost of the cheapest technical geraniol. There was a question about substituting an even more complex mixture for technical geraniol; however, lacking adequate specifications for the oil, consideration of the change was deferred.

Later Tashiro and Fleming (*1954*) found that Java citronella oil-eugenol mixtures were the most attractive and the most practical baits for the European chafer and recommended the 3:1 mixture as an attractant for that insect. The mixture was very attractive to the beetle and to the chafer. It was used by the Department for several years in surveys to determine the presence or absence of the chafer in areas where it was not known to occur. In areas where the beetle was established, capturing large numbers of beetles in traps complicated the chafer survey. Tashiro et al. (*1964*) solved that problem by substituting butyl sorbate for the citronella oil-eugenol bait. The butyl sorbate was equally as attractive to the chafer as the citronella oil-eugenol mixture, but its relative attractiveness to the beetle was only 2 percent.

Anethole

Source, Composition, and Specifications

Anethole is the principal constituent of anise and star anise oils and an important constituent of fennel oil. The natural product obtained by the fraction distillation of star anise oil is usually available in limited quantities. Anethole is also made synthetically from domestic pine oil and this type is available in large quantities. The best grade of anethole meets the following specifications of the National Formulary:

Color at or above 23° C.	Colorless to faintly yellow
Congealing point	20°–21° C.
Melting point	22°–23° C.
Solubility in ethyl alcohol	1 part in 2 parts of alcohol
Specific gravity at 25° C.	0.983–0.987
Boiling range (760 mm.)	234°–237° C.[1]
Refractive index at 25° C.	1.558–1.561
Phenols	Trace
Odor	No readily detectable, irritating, phenolic, or empyreumatic odor

[1] National Formulary VI required this boiling range; National Formulary VII permitted 231°–237° C.

The physical properties of the N.F. product closely agree with those of pure anethole, an unsaturated phenol with an empirical formula of $CH_3CH{:}CHC_6H_4OCH_3$ and a boiling point of 235.3° C. at 760 mm.

In 1945 N.F. anethole was quoted at $2.20 per pound, whereas a technical grade not quite meeting these specifications was quoted at 65.7 cents per pound (Fleming et al. unpublished). After consultation with the producer of technical anethole, Chisholm (unpublished) developed the following specifications for technical anethole:

Color at or above 23° C.	Colorless to faintly yellow
Melting point	18°–23° C.
Solubility in ethyl alcohol	1 part in 2 parts of alcohol
Specific gravity at 25° C.	0.979–0.987
Boiling range (760 mm.)	230°–240° C.
Refractive index at 25° C.	1.548–1.561
Phenols	Trace
Odor	No readily detectable, irritating, phenolic, or empyreumatic odor

Mixtures of Anethole and Eugenol

Fleming et al. (unpublished) found that anethole and oils containing this compound were poor attractants for the beetle. The relative attractiveness of natural anethole was 8 percent, synthetic anethole 16 percent, and fennel and star anise oils 3 percent. The relative attractiveness of the 9:1 fennel oil-eugenol mixture was 35 percent and the 9:1 mixture of star anise oil and eugenol 19 percent. Arcol,[3] obtained during the production of anethole from pine oil and containing 15 to 20 percent of anethole and methyl chavicol, was also a poor attractant. The relative attractiveness of the 9:1 mixture of Arcol and eugenol was 15 percent and the 4:1 mixture 13 percent.

The addition of eugenol to the natural and synthetic anetholes greatly enhanced their attractiveness. The relative attractiveness of the 9:1 mixture of N.F. natural anethole and U.S.P. eugenol was 76, the 3:1 mixture 78, and the 1:1 mixture 74 percent. The relative attractiveness (percent) of the 19:1 mixture of N.F. synthetic anethole and eugenol was 115, 9:1 mixture 101, 4:1 mixture 106, 3:1 mixture 121, 3:2 mixture 97, 1:1 mixture 77, and 2:3 mixture 83. The relative attractiveness of the 19:1 mixture of technical geraniol and eugenol was 101, 9:1 mixture 98, and 4:1 mixture 93 percent. (Fleming and Chisholm *1944;* Fleming and Maines unpublished; Fleming et al. unpublished; Langford and Cory *1946;* Muma et al. *1945*)

Fleming and Chisholm (*1944*) recommended the 9:1 anethole-eugenol mixture as a substitute for the geraniol-eugenol mixture, principally because since 1941 it had become increasingly difficult to obtain the desired grade of geraniol at a reasonable cost. In 1946 Fleming et al. (*1946*) recommended anethole, derived from pine oil and meeting the requirements of the National Formulary, or the technical grade of that material, which was cheaper. The 9:1 technical anethole-U.S.P. eugenol mixture has been used in the survey program of the Department since 1945. It was recommended for general use by Fleming et al. (*1946*), the U.S. Bureau of Entomology and Plant Quarantine (*1949*), and Fleming (*1955, 1958, 1960, 1963*).

[3] Trade names are used in this publication solely to provide specific information. Mention of a trade name does not constitute a warranty or an endorsement of the product by the U.S. Department of Agriculture to the exclusion of other products not mentioned.

Caproic acid, phenyl ethyl acetate, phenyl ethyl butyrate, phenyl iso-valerate, and iso-valeric acid were added to anethole-eugenol mixtures to enhance their attractiveness. The relative attractiveness (percent) of the 2:1:2 mixture of anethole, eugenol, and caproic acid was 133 (Langford and Cory *1946*), 3:1:6 mixture 176 (Fleming et al. unpublished), 6:1:3 mixture 202 (Fleming et al. unpublished), and 9:2:9 mixture 246 (Langford and Cory *1946*). The relative attractiveness (percent) of other mixtures containing three components was as follows: The 8:1:1 mixture of anethole, eugenol, and phenyl ethyl acetate 133 (Langford and Gilbert *1949*); 8:1:1 mixture of anethole, eugenol, and phenyl ethyl butyrate 84 and 18:1:1 mixture 114 (Langford and Cory *1946*); 8:1:1 mixture of anethole, eugenol, and phenyl iso-valerate 88 (Langford and Cory *1946*); and 9:1:40 mixture of anethole, eugenol, and iso-valeric acid 79 (Langford and Cory *1946*).

The relative attractiveness (percent) of mixtures with four or five components was as follows: The 12:1:6:1 mixture of anethole, eugenol, caproic acid, and phenyl ethyl butyrate 144 (Fleming et al. unpublished) and 9:1:9:1 mixture 279 (Langford and Cory *1946*); the 8:3:8:3:8 mixture of anethole, eugenol, caproic acid, phenyl ethyl butyrate, and iso-valeric acid 205 (Langford and Cory *1946*).

These preliminary tests indicated several possibilities of enhancing the attractiveness of anethole-eugenol mixtures. The simplest method was to replace half of the anethole in the 9:1 mixture with caproic acid. None of these mixtures were tested more extensively and none of them were recommended.

Mixtures of Anethole Not Containing Eugenol

Three eugenol-bearing oils—bay, clove, and pimenta—were substituted for U.S.P. eugenol in the binary mixtures of anethole and eugenol. The relative attractiveness of the 9:1 anethole-bay oil mixture was 37, 4:1 mixture 33, and 3:1 mixture 27 percent. When clove oil was substituted, the relative attractiveness of the 9:1 mixture was 53, 4:1 mixture 51, and 3:1 mixture 55 percent. The results with anethole-pimenta oil mixtures were more promising. The relative attractiveness of the 9:1 mixture was 105, 4:1 mixture 105, 3:2 mixture 101, and 2:3 mixture 113 percent.

The relative attractiveness of the 1:1 mixture of anethole and caproic acid was 58 percent (Langford and Cory *1946*). It was 76 percent with the 6:3:1 mixture of anethole, caproic acid, and phenyl ethyl butyrate (Fleming et al. unpublished) and 95 percent with the 9:9:2 mixture of these components (Langford and Cory *1946*). It was 120 percent with the 4:4:3:4 mixture of anethole, caproic acid, phenyl ethyl butyrate, and iso-valeric acid (Langford and Cory *1946*).

If eugenol had to be substituted, the most promising mixtures were the 9:1 mixture of anethole and pimenta oil and the 9:9:2 mixture of anethole, caproic acid, and phenyl ethyl butyrate.

Aliphatic Acids

Tests were conducted to determine the attractiveness of the saturated aliphatic acids and one unsaturated acid, oleic acid. Formic acid has an irritating odor, acetic acid a sharp penetrating odor, and propionic acid a pungent perspiration-like odor; butyric, valeric, and caproic acids have disagreeable rancid odors; and palmitic, stearic, and oleic acids are almost odorless. All these acids were poor attractants. Their relative attractiveness (percent) was as follows: Formic 3, acetic 3, propionic 33, butyric 13, n-butyric 4, iso-butyric 5, valeric 29, caproic 27, n-caproic 25, iso-caproic 35, palmitic 15, stearic 4, and oleic 4. (Langford et al. *1943;* Fleming et al. unpublished)

Caproic Acid

In 1946 pure caproic acid cost about $35 per kilogram. The technical product, produced by a fermentation process, cost $1.50 to $3.25 per pound in 100-pound lots. There were no specifications for technical caproic acid. (Fleming et al. unpublished)

The addition of U.S.P. eugenol to technical caproic acid enhanced its attractiveness. Fleming et al. (unpublished) found that the relative attractiveness of the 9:1 mixture of the acid and eugenol was 61 percent, whereas the 4:1 mixture was 53 percent. However, there were great variations in the attractiveness of acid-eugenol mixtures made with technical caproic acid from different producers. The relative attractiveness of the 9:1 mixture ranged from 39 to 82 percent and a similar variation was found with the 4:1 mixture. Muma et al. (*1945*) found that the 9:2:9 mixture of caproic acid, eugenol, and mineral oil was 81 percent as attractive as the standard geraniol-eugenol mixture.

The relative attractiveness of the 1:1 mixture of caproic acid and pimenta oil was 72 percent and the 1:1 mixture of caproic acid and sassafras oil 49 percent (Langford et al. *1943*).

The relative attractiveness of the 4:1 mixture of caproic acid and phenyl ethyl butyrate was 124 percent, whereas the 18:1:1 mixture of caproic acid, phenyl ethyl butyrate, and phenyl iso-valerate was 78 percent. When mineral oil was added as a diluent, the relative attractiveness of the 2:1:2 mixture of caproic acid, phenyl ethyl butyrate, and mineral oil was 77 percent and the 1:1:6 mixture 106 percent. (Langford and Cory *1946*)

Mixtures of caproic acid, eugenol, and phenyl ethyl butyrate or phenyl iso-valerate were very attractive to the beetle. The relative attractiveness of the 8:1:1 mixture of caproic acid, eugenol, and phenyl ethyl butyrate was 284 percent and the 18:1:1 mixture 301 percent. The relative attractiveness of the 18:1:1 mixture of caproic acid, eugenol, and phenyl iso-valerate was 264 percent. (Langford and Cory *1946*)

Langford and Cory (*1946*) recommended the 18:1:1 mixture of technical caproic acid, U.S.P. eugenol, and phenyl ethyl butyrate as a substitute for the recommended geraniol-eugenol bait because of its simplicity, economy, and higher attractiveness to the beetle. It is not known to what extent this mixture was used as an attractant.

Valeric Acid

Langford et al. (*1943*) found that the relative attractiveness (percent) of a 9:1 mixture of valeric acid and bay oil was 75, the 1:1 mixture of the acid and linaloe oil 55, 9:1 mixture of the acid and pimenta oil 68, and 9:1 mixture of the acid and sassafras oil 69.

Esters

The few esters tested had a low attraction to the beetle. The relative attractiveness (percent) of amyl acetate was 8 (Langford et al. *1943*), iso-amyl valerate 4 (Fleming et al. unpublished), butyl sorbate 2 (Tashiro et al. *1964*), citronyl acetate 7 (Fleming et al. unpublished), geranyl acetate 36 (Metzger unpublished; Metzger and Maines *1935*), methyl salicylate 8 (Langford et al. *1943*), and phenyl ethyl acetate 5 (Fleming et al. unpublished).

The mixtures of the esters and U.S.P. eugenol were more attractive, but only mixtures containing phenyl ethyl acetate or phenyl ethyl butyrate attracted as many as or more beetles than the standard geraniol-eugenol bait. The relative attractiveness (percent) of the ester-eugenol mixtures was as follows:

Composition of bait by volume and relative attractiveness (percent)[1]	*Source*
iso-Amyl valerate + eugenol 9:1 (53)	Fleming et al. unpub.
Butyl carbitol acetate + eugenol 9:1 (27)	Do.
Ethyl caproate + eugenol + mineral oil 9:2:9 (58)	Muma et al. *1945*.
Geranyl acetate + eugenol 10:1 (75)	Metzger unpub., Metzger and Maines *1935*.
Methyl anthranilate + eugenol 9:1 (16)	Fleming et al. unpub.
Methyl salicylate + eugenol 9:1 (20)	Do.
Phenyl ethyl acetate + eugenol 8:1 (108), 1:9 (99)	Langford and Gilbert *1949*.
Phenyl ethyl butyrate + eugenol 1:1 (123), 1:9 (145)	Langford and Cory *1946*.

[1] Parenthetical numbers in percent.

The mixtures containing phenyl ethyl acetate and phenyl ethyl butyrate were not tested more extensively.

Eugenol

Composition, Source, and Specifications

Commercial eugenol is usually obtained by the fractional distillation of clove oil, but it may be obtained from cinnamon oil. The specifications of the U.S. Pharmacopoeia grade, which was used in the baits, are as follows (Fleming et al. *1940a*):

Color and odor	Colorless to pale yellow thin liquid with strong aromatic odor of cloves
Specific gravity at 25° C.	1.064–1.070
Solubility in 70 percent ethyl alcohol	1 part in 2 parts of alcohol
Boiling range (760 mm.)	250°–255° C.

The U.S.P. product is practically pure eugenol, an unsaturated phenol with the empirical formula $CH_2{:}CHCH_2C_6H_3(OCH_3)OH$. The physical properties of U.S.P. eugenol are essentially the same as those of pure eugenol. With these standardized specifications, practically the same eugenol can be obtained year after year.

Eugenol Alone

Richmond (*1927*) reported that eugenol had about one-sixth the attractiveness of technical geraniol. Later he (*1931*) reported that eugenol attracted only 40 percent as many beetles as clove oil, which contains a large amount of the phenol. That appraisal of eugenol as a poor attractant was accepted for several years. In additional tests in 1939 Fleming et al. (unpublished) found that U.S.P. eugenol was at least two-thirds as attractive as the geraniol-eugenol standard bait. Langford et al. (*1943*) rated its relative attractiveness 63 percent. Fleming et al. (unpublished) found the relative attractiveness of clove oil was 17 percent and Langford et al. (*1943*) 21 percent. In view of these discrepancies, further attention was given to the attractiveness of eugenol.

In more extensive tests by Fleming et al. (unpublished), the relative attractiveness of pure eugenol varied from 67 to 77 percent with an average of 70 percent. The relative attractiveness of U.S.P. eugenol obtained from clove oil varied from 47 to 74 percent with an average of 68 percent, whereas the U.S.P. eugenol obtained from cinnamon oil varied from 41 to 83 percent with an average of 64 percent. The pure eugenol is too costly to recommend for general use in a bait, but it is an excellent standard bait, except for its level of attractiveness. Fleming et al. (*1940a*) recommended U.S.P. eugenol obtained from clove oil as a component of beetle baits.

Mixtures of Eugenol With Other Compounds

Fleming et al. (unpublished) diluted eugenol with ethylene glycol and dimethylphthalate to determine how dilution modified its attractiveness. In comparison with eugenol, the relative attractiveness (percent) of the 4:1, 3:2, 2:3, 1:4, and 1:9 mixtures of eugenol and ethylene glycol was 100, 97, 91, 75, and 56, respectively. The results indicated that eugenol could be diluted 3:2 with ethylene glycol without modifying its attractiveness, but the mixtures were poor in that they separated into two layers during exposure in the field. The 3:1 mixture of eugenol and dimethylphthalate had only one-half the attraction of eugenol.

When eugenol was converted to iso-eugenol by boiling with alcoholic potash, the position of the double linking in the side chain was altered and the attractiveness was destroyed. The relative attractiveness of iso-eugenol was only 6 percent (Fleming et al. unpublished).

Eugenol has the property of enhancing the attractiveness of many odoriferous substances, including iso-amyl valerate, anethole, anise oil, caproic acid, citral, citronella oil, citronellal, citronellol, geraniol, geranyl acetate, lemon oil, methyl salicylate, phenyl ethyl acetate, phenyl ethyl alcohol, pimenta oil, safrole, sassafras oil, and alpha terpineol. With few exceptions, all the more attractive baits contained eugenol.

Substitutes for Eugenol

Only a few mixtures of anethole, caproic acid, or geraniol with components other than eugenol had an attractiveness about equivalent to the geraniol-eugenol standard bait. The relative attractiveness (percent) of the 9:9:2 mixture of anethole, caproic acid, and phenyl ethyl butyrate was 95 (Langford and Cory *1946*), 4:4:3:4 mixture of anethole, caproic acid, phenyl ethyl butyrate, and isovaleric acid 120 (Langford and Cory *1946*), and 9:1 mixture of anethole and pimenta oil 105 (Fleming and Chisholm *1944*).

The relative attractiveness of the 4:1 mixture of caproic acid and phenyl ethyl butyrate was 124 percent (Langford and Cory *1946*).

The relative attractiveness (percent) of technical geraniol when mixed with other compounds was as follows: 9:1 with butyl carbitol acetate 96 (Fleming et al. unpublished), 4:1 with caproic acid 103 (Langford and Cory *1946*), 10:1 with clove oil 98 (Fleming et al. unpublished), 10:1 with phenyl ethyl alcohol 98 (Metzger and Maines *1935*; Metzger unpublished), 9:1 with pimenta oil 103 (Fleming and Chisholm *1944*), and 9:1 with alpha terpineol 99 (Fleming et al. unpublished).

Other Attractants

The baits without anethole, caproic acid, citronella oil, eugenol, or geraniol had a relatively low attraction to the beetles, except rhodinol, an unsaturated alcohol closely related to geraniol. The relative attractiveness of rhodinol was 109 percent (Metzger unpublished).

The baits without these six components had a relative attractiveness as follows:

Composition of bait by volume and relative attractiveness (percent)[1]	*Source*
Bay oil + phenyl ethyl alcohol 1:9 (64)	Fleming et al. unpub.
Bay oil + pimenta oil 1:1 (44)	Langford et al. *1943*.
Bay oil + sassafras oil 1:1 (31)	Do.
Cinnamic aldehyde + phenyl ethyl alcohol 9:1 (41)	Fleming et al. unpub.
Clove oil + phenyl ethyl alcohol 1:9 (50)	Do.

Composition of bait by volume and relative attractiveness (percent)[1]	*Source*
Clove oil + phenyl ethyl alcohol + pimenta oil 18:1:1 (34)	Langford et al. *1943.*
Geranyl acetate (36)	Metzger and Maines *1935.*
Palmarosa oil (66)	Fleming et al. unpub.
Pimenta oil (54)	Langford et al. *1943.*
Pimenta oil + ethyl alcohol 1:1 (64), 1:9 (48)	Langford et al. *1943,* Fleming et al. unpub.
Pimenta oil + propionic acid 1:1 (43)	Langford et al. *1943.*
Pimenta oil + sassafras oil 1:1 (57)	Do.
Pimenta oil + valeric acid 1:9 (68)	Do.
Plum leaf oil (35)	Metzger unpub.
Propionic acid (33)	Langford et al. *1943.*
Sesquiterpene alcohols (55)	Metzger and Maines *1935,* Fleming et al. unpub.
Valeric acid (29)	Langford et al. *1943.*
Valeric acid + bay oil 9:1 (75)	Do.
Valeric acid + linaloe oil 1:1 (55)	Do.
Valeric acid + sassafras oil 9:1 (69)	Do.

[1] Parenthetical numbers in percent.

FERMENTED BAITS

Since the beetle is strongly attracted to decaying fruit, the reports by Spuler (*1927, 1927a*) on the attraction of fermented apple juice to the codling moth (*Carpocapsa pomonella* (L.)) stimulated tests with fermented baits as attractants for the beetle.

Anderson (unpublished) and Van Leeuwen et al. (*1928*) suspended stew pans, each holding about a quart of various fermented or unfermented baits, from trees in an infested orchard, using 20 or more pans for each bait. The beetles coming to the pans usually fell into the liquid bait and were not able to escape. The average number of beetles captured per pan with the different baits during a period of 3 or 4 days was as follows:

Fermented bait	*Number of beetles caught per pan*
Malt sirup	3,432
Apple juice	3,230
Cane sugar sirup	2,147
Orange juice	1,975
Prune juice	677
Unfermented bait	
Corn sirup	668
Apple juice	364
Cane sugar sirup	253
Rock candy sirup	162
Water	([1])

[1] Occasional beetle.

Fermented malt sirup and fermented apple juice were the most attractive to the beetles. During 9 hours of beetle activity, the 20 pans with fermented apple juice captured 47,350 beetles.

No comparative tests were conducted to determine the relative attractiveness of the fermented bait and the standard geraniol-eugenol mixture. Later Langford et al. (*1943*) found that unfermented apple juice attracted 31 percent as many beetles as the geraniol-eugenol mixture. It might be surmised that the attractiveness of fermented malt sirup and fermented apple juice would compare favorably with the geraniol-eugenol mixture. The tests with fermented baits were not continued, probably because a bait of this type did not appeal to the general public.

SEX ATTRACTANT

In nature the male beetle is strongly attracted to female beetles, but female beetles in confinement are not attractive. Fleming (unpublished) confined virgin and field-collected females and beetles of both sexes in perforated cylinders of traps designed to hold the attractant. Traps baited with the living beetles captured no more beetles than unbaited traps, which caught a few beetles. When cages covered with wire cloth were placed over plants on which beetles were feeding, most of the beetles left the plants and went to the top and the sides of the cage to escape. Although many beetles came to uncaged plants in the vicinity, few came to the cages.

The reaction of free-flying beetles to confined individuals contrasts to that of the gypsy moth (*Porthetria dispar* (L.)). Collins and Potts (*1931, 1932*) found that the male moths were strongly attracted to confined virgin females, flying in some instances more than 2 miles to them. At first traps baited with living females were used in the survey program, but the possibility of the moths escaping in uninfested areas forced discontinuance of the practice. Traps baited with the last two abdominal segments of the female or extracts of those segments were effective in attracting male moths.

Attempts to extract an attractive substance from female beetles were not successful. Richmond (*1931*) reported that extracts of the abdomens of male and female beetles were not attractive. Fleming et al. (unpublished) in 1942 found that acetone, benzene, ethyl alcohol, and petroleum ether extracts of virgin and field-collected female beetles were not attractive. Traps baited with these extracts captured only an occasional beetle as did the unbaited traps.

Ladd et al. (unpublished) soaked virgin female beetles for several days in 95 percent ethyl alcohol. Then the bodies were macerated in the alcohol and the solution was filtered. Each 1.25 ml. of the alcohol contained the material extracted from one beetle (extract A). A part of this extract was concentrated under reduced pressure at room temperature to one-fifth its original volume (extract B). A 4:1 mixture of extract A and glycerin was tested in competition with a 4:1 mixture of ethyl alcohol and glycerin and a 9:1 mixture of anethole and eugenol.

During a 12-day period 93 percent of the beetles captured were in traps baited with anethole-eugenol, 4.6 percent in traps with extract A and glycerin, and 2.4 percent in traps with alcohol and glycerin. In tests with the concentrated extract B, 82.7 percent of the beetles captured were in traps baited with anethole-eugenol, 4.7 percent in traps with extract B, and 6.6 percent in unbaited traps. The ratio of male to female beetles captured was 1:1.01 with anethole-eugenol, 1:1.23 with extract A and glycerin, 1:1.24 with alcohol and glycerin, 1:1.79 with extract B, and 1:1.23 with unbaited traps, showing that the extracts had no special attraction for the male beetles.

Possibly the attractive substance is released by the female when she is stimulated by her environment and not at other times. The substance apparently is not soluble in acetone, benzene, ethyl alcohol, or petroleum ether, or if soluble it is decomposed rapidly.

OVIPOSITIONAL CHEMOTROPISM

During a survey, grubs were observed to be more numerous in an area on a golf course where field garlic (*Allium vineale* L.) was growing than in other areas. The odor of the plant was thought to have attracted beetles to lay eggs in the vicinity.

Lipp (*1928, 1929*) conducted some preliminary experiments with allyl sulfide, a compound with a garliclike odor. Fifty beetles of each sex were introduced into a cage over turf and the compound in a small cup was placed near one corner of the cage. The odor of the undiluted chemical was apparently repellent because no eggs were deposited near the cup. When 1- and 2-percent solutions of allyl sulfide in ethyl alcohol were placed in one corner of the cage and ethyl alcohol was in the diagonally opposite corner, most of the eggs were deposited near the cups containing the allyl sulfide and none near the ethyl alcohol, indicating that a weak garliclike odor did affect the females in selecting a spot for oviposition.

Although there would be some advantage in inducing the female beetle to deposit her eggs in a selected area, no additional experiments were conducted with ovipositional chemotropism.

TRAPS WITH ATTRACTIVE BAITS

Electrical Traps

Several electrical traps for electrocuting flies and mosquitoes were on the market in 1927, but they were small and ineffective in killing beetles. In preliminary experiments with alternating electrical currents of various frequencies and voltages, Mehrhof (unpublished) and Mehrhof and Van Leeuwen (*1930*) demonstrated that beetles flying between parallel charged wires were readily electrocuted by a current with a frequency of 60 cycles and a potential of 10,000 to 12,000 volts. The optimum distance between the parallel wires was five-eighths inch. The wires at that distance did not impede the flight of a beetle between them, but the insect could not pass without touching at least one of them. The distance between the wires was just sufficient to prevent sparking, except when a beetle flew between them. The destructive electrical discharge passed from one wire through the body of the insect to the adjacent wire. The elytra of many beetles were burned from their bodies, the wings were usually damaged, and sometimes holes were burned in the thorax or abdomen.

An experimental trap, 3 feet square and 3 feet high, was constructed on a wooden frame with bare wire stretched in parallel strands on the sides and top. The alternate strands were connected so there would be a potential of 10,000 to 12,000 volts between any two adjacent strands. The trap was operated from a 110-volt, 60-cycle alternating current and consumed 0.13 to 0.18 kilowatt per hour, depending on the number of beetles touching the wires. Peach twigs sprayed with emulsified geraniol were suspended each day in the center of the trap to attract beetles.

Beetles were attracted at times from plants one-fourth mile away. Practically all coming into contact with the trap were killed. Less than 3 percent of the beetles collected on the ground near the trap were alive 48 hours later. The trap placed 4½ feet above the ground in a peach orchard electrocuted 592 beetles per hour. When it was elevated 9 feet above the ground, 935 beetles per hour were killed in the peach orchard and 857 per hour in an open field.

The use of the electrical trap made by Mehrhof and Van Leeuwen (*1930*) was restricted by the availability of 110-volt electrical power. Rex (unpublished) developed a trap that operated on a 6-volt storage battery. The battery supplied current for the primary winding of a jump spark coil. The secondary winding of a 2-inch coil produced a potential of 20,000 volts that killed about 75 percent of the beetles flying between two bare wires spaced five-eighths inch apart; a 4-inch coil produced a potential of 40,000 volts that killed all the beetles. One charging of the battery operated either unit for about 8 hours. The wires were stretched on a wooden frame, 4 feet high and 12 feet long, which was mounted on two saw horses about 3 feet above the ground. A 30 percent geraniol emulsion was atomized by a nozzle in the center of the upper rail of the trap by means of a 6-volt pump to attract beetles. The trap was placed across the path of the flight of beetles.

The trap was set up in a heavily populated area on a clear day when the temperature was high. Two minutes after the atomizer was started a steady stream of beetles moved toward the trap. With a potential of 20,000 volts between the adjacent wires many beetles attempting to fly between the wires were stunned but recovered sufficiently to continue their flight to a cornfield 100 yards beyond the trap. Other beetles alighting on the wires were electrocuted and remained clinging to them, causing a continuous discharge at these points. It was necessary to shut off the current to remove these beetles. With a potential of 40,000 volts all beetles touching the wires were killed and thrown violently to the ground.

The electrocution of large numbers of beetles by these experimental traps was spectacular, but with such high voltages they could not be placed unattended in the field. Some manufacturers of electrical traps were impressed by these experimental traps and modified their devices to attract and kill beetles. Metzger (unpublished) tested several of these modified commercial traps. All of them attracted and killed beetles, but being relatively small compared with the experimental traps, the number killed was not impressive even in heavily populated areas. The manufacturers sold only a few of their modified electrical traps for killing beetles, indicating that the public had little interest in such a device.

Mechanical Traps

The first mechanical device for capturing beetles was used in 1924. It consisted of a glass lantern globe mounted on a wooden base, which was attached to a stake, and a funnel was inserted into the upper opening of the globe. Bran bait was scattered on the wooden base as an attractant. Another preliminary trap was a glass jar with a funnel in its opening, and it was suspended from a branch of a tree. The bait was scattered over the bottom of the jar. Both of these crude devices caught beetles, but they were inefficient and impractical. (Richmond and Metzger *1929*; Metzger unpublished)

The results with these and other crude devices stimulated efforts to develop a standard trap to catch large numbers of beetles in the heavily populated areas. Many models differing widely in size, shape, and practability were constructed and tested. In addition to capturing beetles, a trap to be practical had to be simple in design, cheap to construct, and sufficiently durable to withstand exposure to the weather for several weeks. Several hundred models were constructed during the 1930's.

Development of Standard Trap

Trap A.—The best standard trap in 1925 consisted of an unpainted cylindrical galvanized iron bucket 12 inches high and 7 inches in diameter with a funnel fitted snugly into the top of the bucket and a holder for the bran geraniol-eugenol bait slightly less than 7 inches in diameter supported on brackets 5 inches above the bottom of the bucket. The funnel projected through a hole in the center of the bait container and discharged beetles on the bottom of the bucket. A small hole in the bottom of the bucket was for drainage, and a handle was attached to suspend the device from a stake. (Metzger *1928;* Richmond and Metzger *1929*)

The pitch of the funnel and the size of its lower aperture determined the effectiveness of the trap. Metzger (*1928*) found that a funnel with a pitch of 60° was the most effective in capturing beetles that hit the inside of the funnel while in flight or tumbled into the funnel while perched on the rim. An opening three-fourths inch in diameter at the lower end of the funnel permitted beetles to slide easily into the bucket. A smaller opening became clogged with beetles, and a larger opening permitted some of the captured beetles to fly out through the funnel. Several years later Langford et al. (*1940*) confirmed these conclusions. They found that a trap funnel with a pitch of 45° captured 76 percent as many beetles as one of 60° and at 80° only 62 percent as many beetles. A trap with an opening 1 inch in diameter at the bottom of the funnel caught 70 percent as many beetles as one with a $\frac{3}{4}$-inch opening.

The 150 grams of bran bait in this trap contained 3.75 grams of technical geraniol and 0.375 gram of U.S.P. eugenol (Metzger *1928*).

Richmond and Metzger (*1929*) estimated the efficiency of this trap by counting the number of beetles that came to the trap and the number captured. This could be done only in the early morning or in the evening in moderately to heavily populated areas when only an occasional beetle approached the trap. It was not possible to count the beetles when many were flying about the trap. It was estimated that the trap captured 30 percent of the beetles that approached it. Metzger (*1936a*) questioned the accuracy of the observations, and in light of later developments he considered the efficiency of the trap to be much lower.

Trap B.—In preliminary tests in 1926 and 1927 Richmond and Metzger (*1929*) found that trap A painted medium chrome green to blend with the color of the foliage captured more beetles than the unpainted trap. In more extensive tests Van Leeuwen and Metzger (*1930*) found that the green traps caught 45 percent more beetles than the unpainted trap. For several years thereafter the traps were painted a medium chrome green. For more information on the color of beetle traps, see page 62.

Trap C.—The addition of a baffle above the funnel was the next improvement. Richmond and Metzger (*1929*), observing that many beetles attracted to trap A or trap B flew rapidly over the funnel only a few inches above it, attached a piece of sheet tin upright above the funnel. During a 3-hour period 203 beetles flew directly into the funnel, 182 hit the baffle and fell into the funnel, and 190 hit the baffle at such an angle that their flight was merely deflected.

Metzger (*1928*, unpublished) tested several types of baffles and found that the four-winged baffle was the most effective. It was made by fitting two pieces of sheet metal together so that the wings were at right angles to each other. The baffle was soldered to the rim of the funnel and extended 4 inches above it. Metzger (*1936a*) found that trap B equipped with the four-winged baffle painted green caught 34 percent more beetles than the trap without the baffle. Langford et al. (*1940*) confirmed that the four-winged baffle was the best type. It was estimated that trap C caught 1.9 times as many beetles as trap A.

Trap D.—Trap D was the same as trap C, except the amount of geraniol in the 150 grams of bait was increased to 15 grams and the amount of eugenol to 1.5 grams. Van Leeuwen and Metzger (*1930*) found that by increasing the amount of attractant to that extent, trap D captured 160 percent more beetles than trap C. It was estimated that trap D caught five times as many beetles as trap A.

Trap E.—The construction of the trap was modified in 1928 to make it more convenient to operate. The height of the bucket was decreased to 7 inches and a glass jar with a slit in the bottom for drainage was attached to a screw cap on the bottom of the bucket as a receptacle for captured beetles. The lower part of the funnel projected through the bait container, which rested on the bottom of the bucket, and through the screw cap, and it discharged beetles into the jar. The jar heated readily in the sun so that captured beetles survived for only a few hours. The jar had to be emptied at least every other day because the odor of decomposing beetles is somewhat repellent. Trap E was equivalent to trap D in effectiveness. (Metzger *1932, 1934a, 1936, 1936a;* Van Leeuwen and Metzger *1930*)

Rex (*1931, 1932*) overcame the problem of beetles decomposing in the glass jars by substituting receptacles made of wire cloth or perforated metal for the jars. Langford et al. (*1940*) designed other receptacles of perforated metal. Since they were well aerated, the beetles usually lived in them for several days.

Trap F.—Trap F was the same as trap E, except the inside of the funnel and the baffle were white. The remainder of the trap was medium chrome green. The green and white trap caught 87 percent more beetles than trap E. It was estimated that trap F captured 9.4 times as many beetles as trap A. (Metzger *1932, 1936a,* unpublished; Van Leeuwen and Vander Meulen *1931*)

Trap G.—Trap G was the same as trap F, except the outside of the bucket was painted a lighter shade of green than the medium chrome green used previously. It captured 40 percent more beetles than trap F. It was estimated that trap G caught 13.1 times as many beetles as trap A. (Metzger *1936a*, unpublished)

Trap H.—When traps were equipped with a four-winged baffle resting on top of the funnel, some beetles were observed flying under the baffle and escaping. When trap H was modified so that the baffle extended 2 inches into the funnel, it captured 56 percent more beetles. Extending the baffle more than 4 inches above the funnel did not increase the number of beetles caught.

It was estimated that trap H caught 20.5 times as many beetles as trap A. (Metzger *1932, 1936a*)

Trap I.—The standard trap was remodeled in 1932. The bucket was eliminated, the screw cap of the beetle receptacle was soldered to the lower end of the funnel, and a cylindrical bait container of perforated metal with a solid cap on the top and the bottom was mounted in the center section of the baffle, which was cut out to receive it (Metzger *1934a*). The construction of the trap was covered by U.S. Patent 1,968,953 (Metzger *1935a*). This trap equipped with a glass jar beetle receptacle is shown in figure 1 and with a perforated metal receptacle in figure 2.

Trap I, which had the outside of the funnel light green, the inside of the funnel and the baffle white, and the bran bait in the container above the funnel, captured 39 percent more beetles than trap H with the bait in the bucket. It was estimated that trap I caught 28.5 times as many beetles as trap A. (Metzger *1936a*)

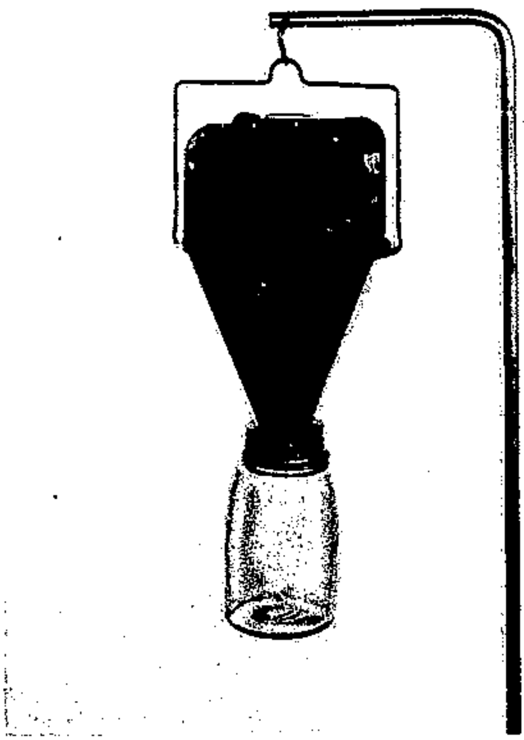

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FIGURE 1.—Standard trap with glass jar for beetle receptacle. Bait is placed in perforated cylinder in baffle. Metal parts are painted chrome yellow with high luster.

Trap J.—Trap J was the same as trap I, except the bran bait was replaced by a 10:1 mixture of geraniol and eugenol that was vaporized from a wick inserted into the bottle holding the mixture. Trap J captured 13 percent more beetles than trap I. It was estimated that trap J caught 32.2 times as many beetles as trap A. (Metzger *1933*)

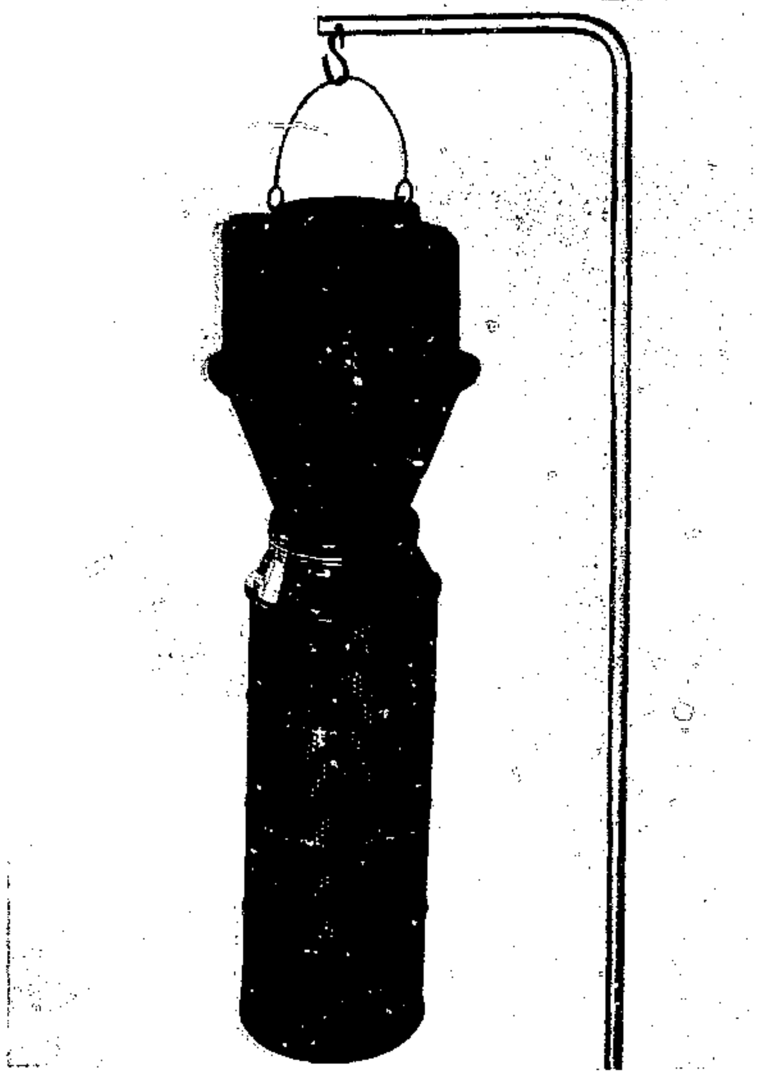

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FIGURE 2.—Standard trap with perforated metal beetle receptacle for use in densely infested areas. Preferred color is yellow throughout.

Trap K.—Trap K was the same as trap J, except it was yellow instead of green and white. It captured 51 percent more beetles than trap J. It was estimated that trap K caught 48.4 times as many beetles as trap A. (Fleming et al. *1940, 1940a*)

Discussion.—Metzger (*1936a*) compared the number of beetles captured in 1926 by trap A in a densely populated area near Riverton, N.J., with the number captured by trap J in an area of that type in Salem County, N.J., in 1933. Most of the A traps caught 1 to 1.5 quarts of beetles daily, whereas several of the J traps captured 40 quarts daily. Langford et al. (*1940*) found that the unpainted, galvanized iron, Maryland modification of trap J caught only 64 percent as many beetles as the trap painted green and white.

Two other interesting though impractical modifications were made in the standard trap. Van Leeuwen and Metzger (*1930*) observed that many beetles flying to trap C collided with the bucket and escaped, although some of them might have been captured later. To overcome this situation, they placed paper coated with a sticky substance made from rosin and castor oil around the bucket. The beetles touching the sticky substance soon extricated themselves, but in the process they became so covered by the material that they could not fly and soon died. The trap with the sticky substance caught and incapacitated 65 percent more beetles than the untreated trap. The sticky substance was considered impractical because it was difficult to handle and the coated paper had to be replaced every few days.

The other change was the modification in the funnel of trap J. Metzger (*1934*) observed that some beetles struck the funnel below the baffle and escaped. When four apertures, each with a flap 1½ inches long, were cut in the side of the funnel and the baffle was extended to the bottom of the apertures, the trap captured 33 percent more beetles. The construction of this trap was covered by U.S. Patent 1,968,954 (Metzger *1935b*). Since the manufacturers were not enthusiastic about this change, modified trap J did not come into general use.

Collecting and disposing of beetles was time consuming in heavily infested areas where large numbers of traps were operated and 5,000 or more beetles were captured per trap daily. To remedy this situation, Langford et al. (*1945*) removed the beetle receptacle and substituted for it a salve box containing a 3:1 mixture of DDT and axile grease or a cotton pad saturated with a 1:1:1 mixture of DDT, mineral oil, and deobase oil. The beetles were discharged from the funnel onto the DDT-treated surface and then dropped to the ground. Ninety-eight percent or more of the beetles coming into contact with the insecticide were killed. Traps equipped with this killing device were used only to a limited extent because the accumulation of poisoned beetles near a trap could be a potential hazard to poultry and wild birds.

Development of Survey Trap

Although several thousand standard traps were used by the Department in surveys beyond the area generally infested by the beetle, they were not well adapted for use in such a program. They were bulky to store and ship, the cost of shipment was high, and the beetle receptacle was much larger than necessary in areas where only a few beetles might be captured during the entire trapping season. The several types of small commercial traps appearing on the market from time to time were unsatisfactory. Metzger (unpublished) found that these small traps captured only 12 to 65 percent as many beetles as the standard trap. Langford et al. (*1940*) also tested several small commercial traps and found that the best one was only 50 perecnt as effective as the standard trap. An efficient small trap was needed that could be stored, shipped unassembled, and assembled easily in the field.

Armstrong and Metzger (*1935*) constructed several models of readily assembled survey traps and were granted U.S. Patent 2,020,283 covering these devices. The best model consisted of a funnel 6 inches in diameter at the top and three-fourths inch at the bottom, a four-winged baffle 6 inches square set 2 inches into the funnel, a pumice block saturated with a 10:1 mixture of geraniol and eugenol mounted in the center of the baffle, and a small can with a capacity of 50 to 100 beetles attached to the bottom of the funnel by means of a screw cap. The entire trap was constructed of lacquered tin to produce it as cheaply as possible.

In 1935 Metzger (unpublished) found that the lacquered survey trap captured only 35 percent as many beetles as the standard green and white trap with a bottle-and-wick dispenser. It was 61 percent as effective as the standard trap with a saturated pumice block to dispense the bait and 83 percent as effective as the standard trap painted aluminum and equipped with the bottle-and-wick dispenser.

In another test he (unpublished) placed 100 traps each of the green and white standard trap with the bottle-and-wick dispenser, the standard trap painted aluminum with the bottle-and-wick dispenser, and the lacquered survey trap with a saturated pumice block at Cape Charles, Va., Pocomoke City, Md., and Salisbury, Md. During the summer 5,312 beetles were captured by these traps at Cape Charles, 786 at Pocomoke City, and 119 at Salisbury. The green and white standard trap captured 50, 49, and 51 percent of the beetles, respectively, at these towns, the standard trap painted aluminum 25, 29, and 25 percent, and the lacquered survey trap 25, 22, and 24 percent. It was evident that the color of the survey trap was an important factor in its poor performance.

In 1936 Metzger (unpublished) tested the lacquered and the green and white survey traps and found that the lacquered trap caught only 70 percent as many beetles. In tests with the green and white survey and the green and white standard traps, both equipped with a saturated pumice block to dispense the bait, the survey trap captured 56 percent as many beetles as the standard trap at Moorestown, N.J., and 75 percent as many beetles at Woodstown, N.J. These tests indicated that the pumice block exposed directly to the weather in the survey trap was not as attractive during the season as the block enclosed in the perforated metal cylinder in the standard trap.

In 1937 the bait dispenser, or the saturated pumice block, of the green and white survey traps was enclosed in a perforated metal cylinder mounted in the baffle, and as an economy measure the beetle receptacle was fastened to the lower end of the funnel by means of tabs. This method of attaching the beetle receptacle was not satisfactory because the receptacle was not held tightly enough against the funnel to prevent the escape of captured beetles. Comparative tests of the survey and standard traps that year were of little value because of this structure defect in the survey trap. (Fleming et al. unpublished)

In 1938 the survey trap was equipped with a bottle-and-wick dispenser set in an aperture in the center of the baffle. The wick was protected from the weather by an inverted metal cone that covered it. The beetle receptacle was held tightly against the funnel by a spring-wire bail. This trap is shown in figure 3. A cheap felt wick was used to vaporize the attractant. When tested in competition with the standard trap equipped with the recommended cotton

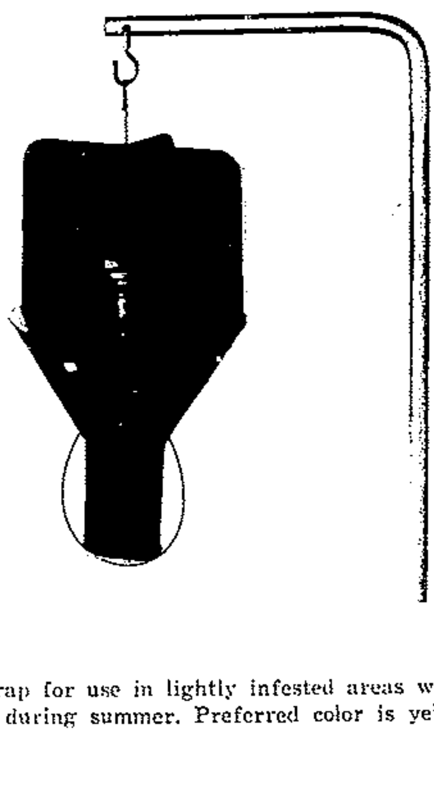

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FIGURE 3.—Survey trap for use in lightly infested areas where only a few beetles are captured during summer. Preferred color is yellow throughout.

wick, the survey trap captured 73 to 88 percent as many beetles as the standard trap. The lower catch by the survey trap was attributed to the felt wick, because the standard trap with that wick also caught fewer beetles. (Fleming et al. unpublished)

In 1939 both the standard and the survey trays were equipped with cotton wicks to vaporize the bait. During a 6-week period the survey trap caught 97 percent as many beetles as the standard trap. Further tests substantiated that the survey trap was equivalent to the standard trap in effectiveness. Since 1939 the survey trap with a cotton wick to vaporize the bait has been used by the Department in surveys outside the area known to be infested by the beetle. After 1940 the survey traps were painted a primary yellow. (Fleming et al. *1940a;* Hadley *1940*)

Fleming et al. (unpublished) modified several hundred of the survey traps by equipping them with a larger beetle receptacle made of perforated metal so that they could be used in areas with denser beetle populations than in the lightly infested areas for which they were originally designed. Langford et al. (*1940*) similarly modified the survey trap.

Bait

The 10:1 mixture of technical geraniol and U.S.P. eugenol was recommended by the Japanese Beetle Laboratory as the attractant in traps from 1928 to 1944, when geraniol became unavailable (Metzger *1928, 1932, 1934a, 1936;* Van Leeuwen and Metzger *1930;* Fleming et al. *1940a*). A 20:2:1 mixture of technical geraniol, U.S.P. eugenol, and phenyl ethyl alcohol was recommended as an alternative bait during 1936–39 (Metzger *1936*). The 9:1 mixture of technical or N.F. anethole obtained from pine oil and U.S.P. eugenol has been recommended since 1944 (Fleming and Chisholm *1944;* Fleming et al. *1946;* Fleming *1955, 1958, 1960, 1963*).

Bait Dispenser

Bran Bait.—The attractant was mixed with sweetened bran to retard its evaporation. For use in the early bucket-type traps, the bran bait was placed in a cylindrical container slightly less than 7 inches in diameter and seven-eighths inch deep, the bottom of which was covered with 16-mesh copper wire (Metzger *1928, 1932*). When the standard trap was remodeled in 1932, the bran bait was placed in a perforated cylinder 2 inches in diameter and 6 inches long, which was mounted in the center of the baffle (Metzger *1934a, 1936*). The bran bait was bulky and decreased in attractiveness as the geraniol and eugenol evaporated. The bran bait had to be replaced every 2 or 3 weeks to maintain an adequate level of attractiveness.

Bottle-and-Wick Dispenser.—The development of the bottle-and-wick dispenser by Metzger (*1933*) for vaporizing the bait was an important improvement, in that sufficient bait could be put into the bottle to last for the trapping season, the amount of liquid remaining in the bottle could be readily seen, and with pure compounds the attractiveness remained at about the same level as long as the wick was saturated. In his preliminary experiments he used a cotton wick one-fourth inch in diameter with 12 fibers running lengthwise enclosed in a woven cotton sheath. The bucket-type traps with the 10:1 geraniol-eugenol mixture dispensed by the 2-inch exposed wick caught 7 percent more beetles than the traps with the bran bait, and those with the 4-inch exposed wick caught 27 percent more beetles during 31 days.

Metzger (*1934a*) recommended the ¼-inch cotton wick exposed 2 inches for use in the standard trap, and later he (*1936*) also recommended a ½-inch wick exposed 1 inch. Fleming et al. (*1940a*) recommended the ¼-inch wick exposed 2 inches, the ½-inch wick exposed 1¼ inches, or the ⅝-inch wick exposed 1 inch, and later Fleming (unpublished) also recommended a ½-inch woven dental roll exposed 1¼ inches. These exposures were for the 10:1 geraniol-eugenol mixture. The exposure might have to be adjusted for baits vaporizing at a different rate. It was the practice to put a narrow metal band around the cotton wicks near the upper end to prevent fraying and thus modifying the rate of evaporation. The cotton dental roll did not fray. The wicks were cut so that when the lower end was resting on the bottom of the bait bottle, the upper end projected the desired distance through the cap of the bottle.

In 1939 a felt wick, approximately three-eighths inch square, was much cheaper than the cotton wick. Fleming et al. (unpublished) found that during a 7-week exposure in traps, the ¼-inch cotton wick exposed 2 inches evaporated 5.46 grams of the 10:1 geraniol-eugenol mixture, whereas the felt wick exposed one-half and 1 inch evaporated 9.74 and 13.83 grams, respectively. However, traps with the ½- and 1-inch exposed felt wicks captured only 63 and 72 percent, respectively, as many beetles as those with the cotton wick.

Pumice and Ceramic Blocks.—Pumice and ceramic blocks saturated with the 10:1 geraniol-eugenol mixture was another method of dispensing the attractant. Metzger (unpublished) tested various grades of imported pumice ranging from hard to soft with textures from fine to coarse and several types of domestic ceramic blocks as dispensers of the bait. Some blocks 1 inch square and 4 inches long, which could be used in the standard trap, evaporated about the same amount of bait and attracted about the same number of beetles as the ½-inch cotton wick exposed 1 inch during 8 weeks in the field. Some blocks 2 inches long absorbed about half the amount of bait and evaporated all of it during 8 weeks. The attractiveness of the shorter blocks was about the same as the ½-inch cotton wick during the first 3 weeks in the field, but after that the attractiveness decreased progressively.

In 1935 Metzger (unpublished) developed the following specifications for pumice and ceramic blocks as carriers of the geraniol-eugenol mixture for use in the survey traps:

(1) The block must be strong enough to withstand ordinary handling and shipping without breakage.

(2) It must be of uniform texture throughout and free from manufacturing defects such as cracks, laminations, and weak areas.

(3) It must not crack or break when exposed to the weather during the summer.

(4) Each block must be in the form of a rectangular prism 1 inch square and 2½ inches long.

(5) Each block when d -- must weigh not less than 60 or more than 70 grams.

(6) It must be impervious to any action by the geraniol- eugenol mixture.

(7) Each block must absorb 13.8 to 19.6 grams of the bait when immersed for 30 minutes. The increase in weight was determined 15 minutes after a block was removed from the liquid.

(8) The impregnated block must not lose less than 47 nor more than 55 percent of the absorbed bait when heated at 150° C. for 48 hours in a standard drying oven.

The Department used several thousand of these impregnated pumice and ceramic blocks in survey traps during 1936, 1937, and 1938. It was not practical to replace the blocks after a 3-week exposure in the field, but there was concern about the decreased attractiveness toward the end of the 6- to 8-week trapping season.

Fleming et al. (unpublished) studied further the evaporation rate of the 10:1 geraniol-eugenol mixture from cotton wicks and pumice and ceramic blocks and the relative attractiveness of these devices in the survey trap. During an 8-week exposure the evaporation from the ½-inch wick exposed 1 inch was relatively constant, averaging 0.8 gram per week. The pumice blocks lost 7.7, 6.9, 2.2, 1.0, and 0.5 grams during the first through the fifth week, respectively, and 0.3 gram per week during the remainder of the exposure. The ceramic blocks lost 5, 4.4, and 1.2 grams the first, second, and third weeks, respectively, and 0.2 to 0.4 gram per week during the remainder of the exposure.

The attractiveness of the ½-inch cotton wick and the pumice and ceramic blocks in the 1938 survey trap was compared with the attractiveness of the ¼-inch wick exposed 2 inches in the standard trap. The bait in the standard trap was changed each week, but in the survey trap the bait was not changed during the 6-week exposure. The relative attractiveness of the ½-inch wick in the survey trap was equivalent to that of the ¼-inch wick exposed 2 inches in the standard trap during that period. The relative attractiveness (percent) of the pumice block was 128, 135, 81, 63, 45, and 35 during the first through the sixth week, respectively. The relative attractiveness (percent) of the ceramic block was 133, 97, 73, 42, 37, and 28 during the first through the sixth week, respectively.

The changes in the evaporation rate of the bait and in the attractiveness of the pumice and ceramic blocks were similar to the changes with the bran bait. In view of these results it was decided to discontinue using the impregnated blocks in the survey traps and to use the bottle-and-wick dispenser.

Beetle Receptacle

To prevent beetles escaping from the receptacle, the lower end of the funnel should not be more than three-fourths inch in diameter and project about 1 inch into the receptacle. The receptacle should be fastened tightly to the bottom of the trap in such a manner that it can be readily removed to empty it. One or more small drainage holes should be made in the bottom of the receptacle so that it will not fill with water during rainy periods. The capacity of the receptacle should be such that it will not overflow with beetles during intervals between their removal. A small receptacle with a capacity of 50 to 100 beetles was ample in lightly infested areas. In densely populated areas a capacity of 2 or more quarts was required.

A Mason jar was first used as the beetle receptacle on the standard trap. A 2-quart jar is about as large as can be used advantageously, because larger jars are too heavy. In densely populated areas it was necessary to empty the 2-quart jars several times daily. When filled, the 2-quart jar held approximately 6,600 beetles.

Metzger (*1932, 1934a, 1936*) devised a method for making a drainage hole in the bottom of the glass jar. A slit was made by holding the bottom of the jar with moderate pressure against an abrasive wheel one-sixteenth inch thick, running at 10,000 linear feet per minute, while a fine stream of water was directed at the point where the cut was being made.

Rex (*1931*) designed a detachable, rigid, wire-mesh receptacle of 3 quarts' capacity to replace the glass jar used on the standard trap. It had a greater capacity without appreciable increase in weight, eliminated the necessity for cleaning, and delayed decomposition of captured beetles. Since the receptacle was well aerated, it did not become hot like the glass jar when exposed to the sun, and the beetles remained alive for several days. Later he (*1932*) replaced the wire-mesh receptacle with 3-quart and 5-gallon perforated metal receptacles. The trap with the large receptacle had legs for standing it on the ground. When filled, the large receptacle held about 66,000 beetles. Langford et al. (*1940*) developed several models of perforated metal receptacles. Actually almost any well-ventilated receptacle is suitable for holding captured beetles, but the perforated metal type is preferred.

The small can attached to the funnel of the survey trap is not as well ventilated as the perforated metal receptacle, but in lightly infested areas where only an occasional beetle was captured, the decomposition of the beetles rarely was a factor.

Reducing Cost of Constructing Traps

One saving in the cost of constructing traps was the trend to decrease the amount of metal in the trap as modifications were made to increase its effectiveness in capturing beetles. The original bucket trap (traps A and B) had 495 square inches of metal. Adding the four-winged baffle above the funnel increased the amount of metal to 551 square inches (traps C and D). Decreasing the height of the bucket to 7 inches and attaching a glass jar as a beetle receptacle decreased the amount of metal to 441 square inches (traps E, F, and G). Extending the baffle 2 inches into the funnel increased the amount of metal to 458 square inches (trap H). Eliminating the bucket decreased the amount of metal in the standard trap to 271 square inches (traps I, J, and K). Excluding the beetle receptacle, the survey trap had only 154 square inches of metal. From trap A to the survey trap, the amount of metal was reduced 69 percent and the effectiveness in capturing beetles was increased 48.4 times.

Traps were constructed of wood, glass, and paper products in the search for a cheaper material than metal. A cheap trap used for only one season might be more desirable than a metal trap that had to be cleaned and repainted each season. Langford et al. (*1940*) constructed wooden traps in the general form of the standard trap and painted them. The wooden traps were 17 percent less effective than the standard trap in capturing beetles. There is a question whether they were any cheaper than the metal traps. Possibly a wooden trap might appeal to boys interested in constructing their own traps.

Metzger (unpublished) constructed an experimental trap entirely of glass. The only metal used was the holder for the bran bait, which was placed on the bottom of the beetle receptacle, a 2-gallon percolator. The glass trap captured 34 percent more beetles than the green standard trap D. However, glass was considered too fragile for the construction of traps.

Langford et al. (*1940*) constructed a standard trap of paraffin-coated painted cardboard. For 23 days about the same numbers of beetles were captured by the cardboard and metal traps. The cardboard traps were not satisfactory because on exposure to weathering they tended to fall apart.

Hadley and Chisholm (unpublished) tested the resistance of 15 types of coated and uncoated paper stock to weathering. The paper stocks were immersed in water for 8 hours and then dried at room temperature. Only one of these paper stocks, a fiber case board, retained its shape. A survey trap constructed of this material retained its shape during a 6-week exposure in the field, and during that period caught 88 percent as many beetles as the metal survey trap. Three traps of heavy waterproof paper board, submitted by manufacturers, were definitely less effective than the metal survey trap in capturing beetles. The best of these caught only 77 percent as many beetles as the metal trap. The trap made of fiber case board painted yellow was recommended in 1943 as a possible substitute for the metal trap, if metal was not available. The Department used traps made of this material in the survey program of 1944 and to some extent in 1945 and subsequent years. Traps made of fiber case board were discarded after exposure in the field.

When metal became more available, the Department returned to the use of metal traps.

Color of Traps

In a preliminary experiment in 1927 Richmond and Metzger (*1929*) found that traps painted a medium chrome green to blend with foliage captured 35 percent more beetles than unpainted traps. In more extensive tests with painted and unpainted traps Van Leeuwen and Metzger (*1930*) found that a trap painted green caught the most beetles. The relative effectiveness (percent) of the other traps, as compared with that of the green trap, was as follows: Brown 93, yellow 89, red 81, blue 76, orange 76, unpainted 69, white 65, indigo 60, black 52, and purple 50. As a result of these tests it was recommended that the traps be painted a medium chrome green.

The commercial traps for public use were many shades of green, varying from light to dark and from bluish green to yellowish green. Metzger (unpublished) found that in comparison with a medium chrome green trap, the relative effectiveness (percent) of traps painted other shades of green was as follows: Olive green 110, dark green 123, chlorophyll green 131, pea green 139, and light green 148. Metzger (*1932*) recommended that the traps be painted a light green.

During the summer of 1930 a company manufacturing beetle traps in Philadelphia, Pa., reported that green traps with white baffles caught more beetles than all-green traps. In a preliminary test Van Leeuwen and Vander Meulen (*1931*) found that in comparison with the all-green trap, the relative effectiveness of a green trap with a white baffle was 140 percent and a green trap with a white baffle and white inside funnel 210 percent. In 1931 Metzger (unpublished) studied further the effectiveness of the beetle trap by changing the color of different parts of the all-green bucket trap to white. In comparison with the all-green trap, the relative effectiveness (percent) of a green trap with white baffle was 166, a green trap with white inside funnel 180, and a green trap with white baffle and white inside funnel 187. One of the unexpected results, in view of the previous tests by Van Leeuwen and Metzger (*1930*), was that the all-white trap captured 39 percent more beetles than the all-green trap. The white trap was less effective with a green baffle or green inside funnel. Metzger (*1932, 1934a, 1936*) recommended painting the baffle and inside funnel white and the other parts of the trap light green. These traps were used for several years.

Fleming et al. (*1940*) tested the survey trap with the various parts painted white, light green, and dark green in competition with the standard trap with the baffle and inside funnel white and the rest light green. In comparison with the green and white standard trap, the relative effectiveness of the all-white, all-light green, and all-dark green survey traps was 97, 82, and 80 percent, respectively. A dark-green baffle and cone on the white trap reduced its relative effectiveness to 78 percent, dark-green inside funnel to 77 percent, and dark-green baffle, cone, and inside funnel to 76 percent. About the same results were obtained when these parts on the white trap were light green. A white baffle and cone on a dark-green trap increased its relative effectiveness to 89 percent and white baffle, cone, and inside funnel to 97 percent. About the same results were obtained with the light-green trap when these parts were white. It was concluded that the color of the baffle, cone, and inside of the funnel was most important. A trap with these parts painted white or green functioned like an all-white or all-green trap, respectively. The color of the outside of the funnel and the beetle receptacle seemed to be of minor importance. In view of these results, there was no basis for the dual-color traps.

In a more fundamental study, Fleming et al. (*1940*) tested the survey trap painted with the primary colors and white in competition with the green and white standard trap. The relative effectiveness (percent) of the traps in capturing beetles was as follows: Red 78, blue 89, white 97, and yellow 151. The striking result was that the yellow trap was 51 percent better than the green and white trap.

Mixtures of the primary colors and white substantiated the superiority of yellow. The addition of red to white or yellow reduced the effectiveness (percent) of these colors as follows: Pink 53, orange 129, and reddish orange 106. The addition of blue to white or yellow reduced the effectiveness (percent) of these colors as follows: Light blue 65, yellowish green 112, medium green 108, bluish green 99, and dark green 83. The addition of white to red, blue, or yellow reduced the effectiveness (percent) of these colors as follows: Pink 53, light blue 65, and light yellow 115. On the other hand, adding yellow to red or blue enhanced the effectiveness (percent) of these colors as follows: Reddish orange 106, orange 109, bluish green 99, medium green 108, and yellowish green 112. These tests established that a pure chrome yellow was the most effective. Whittington and Bickley (*1941*) confirmed that yellow was the best color for beetle traps.

Fleming et al. (*1940a*) recommended that the beetle traps be painted a chrome yellow, using a high luster paint or lacquer. All new and conditioned traps used by the Department in 1940 were yellow. The University of Maryland changed the color of their traps to yellow that year (Whittington and Bickley *1941*). Since then yellow has been the accepted color for beetle traps (U.S. Bureau of Entomology and Plant Quarantine *1949;* Denning and Goff *1944;* Fleming *1955, 1958, 1960, 1968;* Hadley *1940*).

Luster of Traps

In 1931 Metzger (unpublished) demonstrated that a trap that had been used the previous season and had lost much of its luster was only 54 percent as effective as a newly painted trap with a high luster. Fleming et al. (*1940a*) found that traps with a high luster paint or lacquer caught more beetles than those with a dull finish. The effectiveness of the highly lustrous traps decreased as exposure to the weather reduced the luster or changed the color of the pigment. To maintain a trap at its highest efficiency, Metzger (*1932, 1934a, 1936*) and Fleming et al. (*1940a*) recommended repainting the trap when the film of paint had been damaged or had changed appreciably in luster or color.

Density of Beetle Population and Performance of Traps

Most of the studies on the effectiveness of traps were conducted in areas with a moderate to dense population of beetles. The question was raised whether the results obtained under those conditions would apply in lightly populated areas. Metzger (unpublished) tested the relative effectiveness of the green and white and the aluminum traps in 1934 at Moorestown, N.J., where 714,853 beetles were captured and in 1935 at Cape Charles, Va., and Pocomoke, Md., where 4,978 and 612 beetles were caught, respectively, and at Salisbury, Md., where only 90 beetles were captured during the summer. In comparison with the green and white trap, the relative effectiveness of the aluminum trap at Moorestown, Cape Charles, Pocomoke City, and Salisbury was 48, 51, 60, and 50 percent, respectively. There was no relationship between the density of the beetle population and the performance of the traps. About the same results were obtained at Moorestown and Salisbury, where the average capture per trap was 4,467 and less than one, respectively.

Response of Beetles to Baited Traps

Beetles attracted by a baited trap flew upwind toward it. Many of them hit the baffle while in flight, were thrown violently into the funnel, and slid into the beetle receptacle. The collision is unnatural, because beetles in flight have no difficulty in avoiding buildings, poles, and other obstacles in their path. Stimulated by the attractant, the beetles probably did not see the trap soon enough to avoid it. Some beetles approached the trap more leisurely, hovered about it, and then either hit the baffle or alighted on the upper edge of the baffle or the upper rim of the funnel. Most of the beetles on these precarious perches lost their balance and tumbled into the funnel. Some beetles flew over the trap, collided with the outside of the funnel and were thrown to the ground, or were diverted in their flight. Many of them returned to hover about the trap and eventually were caught.

Placement of Traps

The position of a trap with reference to its surroundings is important. In the experimental testing of traps and baits, the traps were suspended from rods in an open field or pasture so that the number of beetles captured by the individual traps would not be affected by infested plants in the vicinity.

In suburban areas fewer beetles were captured by a trap hung in a tree or shrub or suspended from a rod in a rose bed or other favored plants than by a trap hung on a rod several feet from the plants. Many beetles attracted to a trap hung in a tree or shrub ignored the trap and attacked the plants. Van Leeuwen and Metzger (*1930*), Metzger (*1932, 1934a, 1936*), and Fleming et al. (*1934a, 1940a*) found that most beetles were captured when the traps were placed in a sunny location on the windward side 10 to 25 feet from trees, shrubs, and vines favored by the beetle.

Whittington et al. (*1942*) confirmed that conclusion. In their test, 25,448 beetles were captured by traps placed in an open area south of a large rose garden at the following distances:

Distance from garden (feet)	*Beetles caught (percent)*
10	40
160	14
310	14
460	16
610	16

In another test in which traps were placed 10 and 100 feet from roses, grapes, sassafras, and other hosts in six towns, 77 percent of the 65,277 beetles captured were in traps 10 feet from the plants.

The height of the trap above the ground also modified the number of beetles captured. Van Leeuwen and Metzger (*1930*) found that the optimum height was with the rim of the funnel 3 to 4 feet above the ground. Langford et al. (*1940*) confirmed that traps placed higher above the ground caught fewer beetles. In their tests they found that for every 100 beetles captured by a trap with the rim 3½ feet above the ground, 89 and 70, respectively, were caught in traps 4½ and 5½ feet above the ground. The tests of Whittington and Bickley (*1941*) indicated that under some conditions the optimum height might be lower than 3½ feet. In their tests for every 100 beetles taken in traps 3½ feet above the ground, 126, 90, and 68, respectively, were captured at 2½, 4½, and 5½ feet.

Metzger (*1932, 1934a, 1936*) recommended a 7/16-inch iron rod 7 feet long with an 8-inch arm at the upper end to hang the standard trap. A ¼-inch hole was bored 1 inch from the end of the arm. The trap was suspended by passing a wire hook through the hole and around the handle of the trap. Rods made of galvanized iron, although slightly more expensive, did not become rusty during 5 years' use. Langford et al. (*1940*) recommended a rod made from No. 0 galvanized wire, 66 inches long, with the upper 6 inches bent into an arm as a substitute for the 7/16-inch iron rod, because it was equally as satisfactory and much cheaper. A ½-inch rod with an arm 4 inches long was adequate for suspending the lighter survey trap.

Distance Beetles Attracted by Traps

The distance a trap attracted beetles was variable, depending on the environment in which it was placed. In suburban areas where trees, houses, and other structures deflect and impede air movement, the zone of attraction may be small. Most of the beetles captured under these conditions probably came from plants on the premises and adjacent properties. Some suburbanites reported that traps on their premises had increased the beetle populations, whereas others reported no increase. Although traps could be a factor in increasing the population, even without them it was not uncommon for a property with the more attractive host plants to be densely populated and for adjacent properties with less favored plants to have a low population. (Fleming et al. *1940a;* Metzger *1934a, 1936;* Whittington et al. *1942*)

In rural areas with open fields the zone of attraction is larger. Mehrhof and Van Leeuwen (*1930*) reported that at times beetles were attracted to a trap one-fourth mile away. Metzger (*1934a, 1936*) stated that under favorable conditions beetles may be attracted from a distance of 900 to 1,500 feet. Metzger and Maines (unpublished) released 5,000 beetles, marked by dipping in lime-aluminum sulfate spray, in the New Jersey pinewoods about a mile from a large blueberry plantation, and within a few hours 43 of them were caught in traps placed around the plantation. Possibly the major attraction was the ripening berries.

Polivka (*1949*) liberated 8,931 beetles marked with fluorescent pigments in a commercial nursery and 1 to 13 days later captured 174 of them in traps. Traps within 200, 200–300, 300–400, and 400 feet from the liberation point caught 58, 28, 13, and 1 percent, respectively. Of the 16,517 marked beetles released in a village, 190 of them were caught by traps 1 to 36 days later. Traps within 800, 800–1,600, 1,600–3,200, and more than 3,200 feet from the liberation point caught 30, 43, 22, and 2 percent, respectively. Probably most beetles are attracted to a trap within 400 feet.

Effectiveness of Traps in Capturing Beetles

Fleming et al. (*1940a*) estimated that the best standard and survey traps under favorable conditions caught about 75 percent of the beetles attracted to them. This method of estimating efficiency does not consider the beetle population within the area reached by the attractive odor. It is a fairly simple procedure to estimate the number of beetles approaching a trap and to compare that value with the number captured, but it is not so easy to determine the total beetle population in an area. The most practical method was to determine the density of the grub population in an area late in the spring and to use that value as an estimate of the total beetle population.

As a preliminary, Langford et al. (*1940a*) made a soil survey of 16 farms, approximately one farm per square mile, in Cecil County, Md., and determined that the average grub populations per square foot were 14 in pastures, 8.1 in mixed timothy and clover, 8.7 in corn, 8.6 in alfalfa, 3 in orchards, 0.9 in wheat and rye, 0.7 in barley and small grains, 4.2 in soybeans, 4.8 in idle land, and 0.2 in woodlot and nonagriculture land. With this information and the census data on the acreage and kinds of crops on 178 farms, involving 6,749 acres in Cecil County, it was estimated that 396,-833 quarts, or approximately 1,309,548,900 beetles, would emerge on these farms. The 5,338 green and white standard traps, at approximately one per acre, captured 119,029 quarts of beetles, or 30 percent of the estimated population. To check any error from using the census data, the acreage and the kinds of crops were determined for 32 farms, taken at random and involving 3,870 acres. It was estimated that these farms produced 228,431 quarts of beetles, of which 67,774 quarts, or 29.6 percent of the estimated population, were captured.

The following year Langford et al. (*1941*) made surveys to determine the grub population in each crop on 16 selected farms, involving 3,231 acres in Cecil, Kent, and Harford Counties, and estimated that 170,314 quarts of beetles would emerge on these farms. The 1,941 traps caught 46,888 quarts, or 27.5 percent of the estimated population. However, the traps used per acre ranged from 250 on 161 acres to 63 on 350 acres. When the percentage of the estimated population per farm was plotted against the number of acres per trap, it was evident from the curve that on five of the farms the estimated population had been greatly enhanced by migrating beetles. An asparagus grower, for example, caught about five times as many beetles as it was estimated were produced on his farm. The data from the other 11 farms were more consistent and showed a general relationship between the percentage of the population captured and the number of traps per acre. It was estimated that one trap per 1, 2, 3, 4, and 5 acres caught 30, 14, 9, 6, and 4 percent, respectively, of the population. Less than one trap per acre appeared of little value in reducing the population. Since one trap per acre caught about 30 percent of the population, a greater reduction might be expected by increasing the number of traps in that area.

Value of Traps in Controlling Beetle

Surveys Beyond Infested Areas.—Traps are of great value in surveys beyond infested areas to determine the presence or absence of the beetle. In cooperation with State agencies the Department has operated 50,000 to 100,000 traps for many years at airports, freight yards, docks, and other places where the beetle might be carried accidentally. Traps have often captured beetles when a diligent search of the favored food plants in an area failed to reveal their presence. When a beetle was found at an isolated area, additional traps were placed throughout the area to determine the extent of the infestation.

Courtney (*1931*) discussed the use of traps in surveys in Connecticut, Delaware, District of Columbia, Maryland, Massachusetts, New York, Pennsylvania, Rhode Island, and Virginia during the summers of 1929 and 1930. The location of the traps and the number of beetles captured by each were recorded on a map so that it was possible to determine where the population was the densest and probable limits of the infestation. When only a few beetles were captured at a locality, the survey was continued for several years to determine whether the insect became established, and if established to determine the rate of population increase and spread. Usually when the beetle became established in an area several miles from a known infestation, every effort was made by Federal and State agencies to eradicate the infestation or at least to retard the normal increase in population.

Traps in Lightly Populated Areas.—There is some evidence that the capture of the first beetles to invade a locality remote from known infested areas prevented the establishment of the insect. Courtney (*1931*) captured a few beetles at several localities in 1929, but he did not catch any at these localities in 1930, even though no control program had been undertaken. Cory and Langford (*1955*) reported that when the beetle first invaded Maryland and several isolated infestations were found, the capture of the first beetles at an isolated locality often prevented the establishment of the insect for several years. With a reproductive potential of twentyfold to thirtyfold, the capture of female beetles early in the season before little or any oviposition has occurred could eliminate the infestation or at least retard the development of the population.

Traps in Densely Populated Areas.—The N.J. Department of Agriculture and the University of Maryland used traps extensively to reduce the beetle population in densely populated areas. The number of beetles captured in these campaigns was impressive. During the height of the campaign in New Jersey in 1932, Rex (unpublished) placed 2,100 traps on 325 farms in a heavily populated area of 75 square miles in the southern part of the State and captured 160,800 quarts, or about 530,640,000 beetles.

A large-scale program to reduce the density of the beetle population in Maryland was undertaken cooperatively by the University of Maryland and the U.S. Department of Agriculture in 1938. It included trapping, spraying infested plants with insecticides, treating soil with insecticides, colonizing parasites and pathogenic organisms, agriculture adjustment, and education. In 1938 approximately 40,000 traps operated in cities, towns, and villages and on farms in Baltimore, Cecil, Kent, Somerset, and Worcester Counties captured 123,166 quarts, or about 406,447,800 beetles (Langford et al. *1939*). In 1939 approximately 100,000 traps in Maryland caught 104 tons, or approximately 1,050,878,400 beetles (Langford et al. *1940a;* Cory and Langford *1944*). In 1940, 127,122 traps caught 275 tons, or approximately 2,778,765,000 beetles (Langford et al. *1941a*). During the height of the trapping campaign in 1948, when the beetle population was at its peak, about 369 tons, or approximately 3,728,597,400 beetles, were captured (Cory and Langford *1955*). Since then the population density has declined progressively. In 1954 only 19,743,056 beetles were captured in traps in 18 counties (Cory and Langford *1955*).

Although large numbers of beetles were caught in these extensive campaigns, many were left in the densely populated areas to defoliate their favored food plants. There is no technique for determining how much more damage would have occurred if the traps had not been used, but Langford et al. (*1940a*) believed that the traps had been beneficial. The capture of thousands of female beetles before all the eggs had been deposited would cause some reduction in the next brood. In 1938 Langford et al. (*1939*) found that in an area of 19 square miles in Cecil County, Md., the farms on which traps had been placed had 35 percent fewer grubs in the permanent pastures in October than in the previous April, whereas the farms without traps had 2 percent more grubs in their pastures. The entire area had 24 percent fewer grubs in October than the previous April.

Protecting Plants in Densely Populated Areas.—Van Leeuwen and Metzger (*1930*) placed 500 traps at 30-foot intervals on 15 acres of the grounds of Grey Towers, a part of Beaver College near Jenkintown, Pa. During the next few days it was not possible to empty the 1-quart beetle receptacles fast enough to keep them from overflowing with captured beetles. The traps captured 9,004,800 beetles during the 5 weeks they were operated. The beetle's feeding on the trees and shrubs was slight, but most of them were not favored food plants. A survey in September showed that there were about 13 million grubs on the 15 acres. No doubt there would have been many more grubs in the soil if the traps had not been used.

In 1933 the beetle occurred in such large numbers at Shiloh, N.J., that the unsprayed shade and apple trees were defoliated, asparagus was severely injured, extensive feeding occurred on corn leaves before and after the silk appeared, and azaleas, rhododendrons, and narrowleaf evergreens in a nursery were severely injured. These nursery plants are usually immune to beetle attack. Early in July of the following year Metzger (unpublished) placed 100 traps with 2-quart beetle receptacles, the largest then available, along the boundaries of the nursery. Although these receptacles were emptied several times daily, two men were not able to empty them fast enough to prevent some of them from overflowing with beetles. About 5 million beetles were captured during the summer. They did not damage the evergreens, but the deciduous trees, asparagus, and corn in the area were injured just as severely as in the previous summer. Apparently the traps were more attractive than the normally unpalatable evergreens and had protected these plants from injury.

Metzger (unpublished) operated 400 traps experimentally for 3 years in a large field near Woodstown, N.J., and each year captured about 15 million beetles. He observed that a large asparagus field adjacent to the experimental field was only slightly injured by the beetles, whereas other asparagus fields within a radius of 5 miles were severely damaged. In a preliminary experiment he set 48 traps, 10 feet apart, along the westerly side of about one-fourth of an asparagus field near Cohansey, N.J. When the wind blew from the west, the prevailing direction at that locality, thousands of beetles flew from the asparagus to the traps. During a 2-week period the traps caught 500,000 beetles. The asparagus was slightly injured in the part of the field where the traps were located, but the remainder of the field was damaged severely.

Langford et al. (*1940a*) placed 100 traps throughout a 25-acre asparagus field, where the beetles the previous year had severely damaged the plants. The traps caught 4,672,800 beetles and the injury to the asparagus was slight. In another experiment Langford et al. (*1941*) placed 275 traps in another 25-acre asparagus field in an area where the beetle population was very dense. During the next 4 weeks the traps captured 12,157,200 beetles. The damage to the plants was negligible. These experiments demonstrated that asparagus can be largely protected in densely populated areas by placing four or more traps per acre throughout the field.

Cultivated blueberries and cranberries are grown extensively in cleared areas in the pinewoods of southern New Jersey. In 1930 the beetles invaded the blueberry plantation at Whitesbog, then the most extensive in the State, and caused some damage to the foliage and the ripening berries. The grower placed traps around some fields in 1931, but he was uncertain regarding their value. During the spring of 1933 the U.S. Department of Agriculture (Metzger unpublished) in cooperation with the N.J. Department of Agriculture in an extensive survey of the area found that the grubs were most numerous in the grassy areas surrounding the blueberry fields and in the cranberry bogs, but few grubs were in the blueberry fields. A substantial beetle population was in the surrounding woods. Traps placed 0.1, 0.2, 0.3, 0.4, and 0.5 mile from the edge of a blueberry field caught 22,291, 9,736, 6,287, 7,856, and 7,011 beetles, respectively. It was evident that most of the beetles in the blueberry fields came from the woods.

Metzger (unpublished) and Metzger and Maines (unpublished) placed traps about 80 feet apart and 10 to 25 feet away from the outer rows of plants around the blueberry fields. These traps caught 1,294,992 beetles in 1933, 2,182,750 in 1934, and 2,096,398 in 1935. The injury by the beetle in the different fields ranged from light to severe. Most of it occurred in the outer rows of plants. Although many beetles were captured, the traps did not adequately protect the blueberries.

Traps were of no value in protecting early-ripening peaches and apples from beetle attack. Richmond and Metzger (*1929*) hung traps in trees around a small apple orchard. Although over a million beetles were captured during a 3-week period, the trees were practically defoliated and the fruit was destroyed. Metzger (unpublished) placed traps about 8 feet apart in a line 25 feet from an infested peach orchard on the side of the prevailing wind to try to draw beetles from the orchard to the traps. During the 3 days of the test, 11,396 beetles left the orchard and were caught by the traps, but it was estimated that 10,500 beetles flew from or by the traps to the trees.

Many people in suburban areas with a dense beetle population gained considerable satisfaction in trapping beetles on their premises, even though the traps did not protect the favored food plants from insect attack. No doubt the traps decreased the density of the beetle population to some extent, reduced the number of eggs deposited in the soil, and attracted some beetles from the plants, but most property owners were more interested in protecting their plants from attack than catching beetles. For this reason, traps as well as protective sprays and dusts were recommended for suburban areas by Metzger (*1932, 1934a, 1936*), Fleming et al. (*1934a, 1940a*), Hadley (*1940*), Fleming (*1955, 1958, 1960, 1963*), and Cory and Langford (*1955*).

Other Species of Insects Captured

Many species of Lepidoptera, Hymenoptera, Diptera, and Coleoptera were captured in traps baited with the geraniol-eugenol mixture, but usually these insects were considered a nuisance and were discarded because time was not available to sort and preserve them for identification. Only twice were any of the insects other than the Japanese beetle identified.

Richmond and Metzger (*1929*) found 200 specimens of *Chauliognathus marginatus* F., 32 Cerambycidae, 17 *Ophistomis luteicornis* (F.), and 15 *Typocerus velutinus* (Olivier) in the traps.

In 1932 about 400 traps in a pasture near Woodstown, N.J., were baited on June 25 just as the Japanese beetle was beginning to emerge. During the next 5 days before it emerged in large numbers and became the dominant species captured, many species of insects were caught in the traps. Metzger and Sim (*1933*) separated and identified only the Coleoptera.

The Coleoptera species captured are as follows:

Cantharidae—500 *Chauliognathus marginatus* F.

Carabidae—150–200 *Harpalus faunus* Say, 150–200 *H. pennsylcanicus* Say, and 300 *Lebia grandis* Hentz

Chrysomelidae—41 *Acalymma vittata* (F.), 25 *Chrysochus auratus* (F.), and 200 *Leptinotarsa decemlineata* (Say)

Curculionidae—18 *Hypera punctata* (F.) and 250 other weevils

Elateridae—3 *Alaus oculatus* (L.) and 400 *Melanotus* sp.

Hydrophilidae—63 *Sphaeridium bipustulatum* F. and 750 *S. scarabaeoides* (L.)

Scarabaeidae—13 *Anomala* (*Pachystethus*) *lucicola* (F.), 45 *Aphodius fimetarius* (L.), 10 *A. fossor* (L.), 25 *A. haemorrhoidalis* (L.), 175 *Bozhynus gibbosus* (DeG.), 300 *Cotinus nitida* (L.), 90 *Cyclocephala borealis* Arrow, 25 *Dichotomius carolinus* (L.), 1 *Diplotaxis sordida* (Say), 250 *Dyscinetus trachypygus* (Burm.), 1 *Euphoria fulgida* (F.), 14 *E. herbacea* (Oliv.), 500 *Macrodactylus subspinosus* (F.), 30 *Onthophagus hecate* Panz., 16 *O. nuchicornis* (L.), 12 *O. pennsylcanicus* Harold, 5 *Pelidnota* *punctata* (L.), 200 *Phyllophaga ephilida* (Say), 15 *P. fervida* (F.), 125 *P. futilus* (LeC.), 120 *P. hirticula* (Knoch), 5 *Serica* sp., and 11 *Trox insularius* Chev.

Silphidae—11 *Silpha americana* L.

ATTRACTIVE SPRAYS

Repellency of White Deposits on Foliage

One of the problems in developing residual sprays for killing large numbers of beetles was the repellency to the beetle of conspicuous deposits of toxic and nontoxic white materials. By comparing the beetle populations on sprayed and unsprayed trees in a young peach orchard, Van Leeuwen et al. (*1928*) and Van Leeuwen (*1932*) reported the following results with sprays:

Material (pounds) per 100 gallons of water	*Repellency to beetle (percent)*
China clay (6)	87
Lead arsenate (6)	77
Chalk (6)	74
Calcium arsenate (6)	71
Slaked lime (8)	69
Basic lead arsenate (12)	61
Barytes (6)	38

Because of its repellency, Davis (*1920*) recommended 6 pounds of lead arsenate in 100 gallons of water to protect plants from beetle attack. Hadley (*1922*) recommended 4 to 6 pounds of the arsenical. Kelley and Moore (*1923*), finding that 4 pounds of lead arsenate did not give adequate protection, recommended 8 pounds with 4 pounds of wheat flour as a sticker. Smith and Hadley (*1926*) recommended 6 pounds of lead arsenate and 4 pounds of wheat flour, a combination that was used for many years.

Hydrated lime was recommended for several years as a substitute for lead arsenate on early-ripening fruit and for use about the home yard where the arsenical could not be used (Van Leeuwen *1932a;* Fleming et al. *1934, 1934a*). The deposit of lime was readily removed by rain and frequent applications had to be made to protect plants. Lipp and Osburn (*1935*) found a mixture of 20 pounds of hydrated lime and 3 pounds of aluminum sulfate per 100 gallons of water produced a water-resistant residue. Metzger and Lipp (*1936*) found that two or three applications of the lime spray during the flight of the beetle were usually sufficient to protect fruits and vegetables. Although the plants were protected from injury by the lead arsenate and the lime, the lead arsenate killed only a few beetles and the lime none.

Lead Arsenate

Toxicity to Beetle

Van Leeuwen (*1927*) found a small dosage of lead arsenate, ranging from 0.0035 to 0.0156 mg., was fatal within 42 to 67 hours after a beetle began to feed on sprayed foliage. Little feeding was required for a beetle to obtain a lethal dosage. The area of both the upper and lower surfaces of a leaf eaten to obtain a fatal dosage was 90, 74, and 48 sq. mm. with foliage sprayed with 2, 6, and 12 pounds of lead arsenate, respectively, in 100 gallons of water.

Van Leeuwen (*1932*) caught beetles as they left the foliage of apple, grape, and sassafras after the plants had been sprayed with 6 pounds of lead arsenate and 4 pounds of wheat flour per 100 gallons of water, placed them in wire cages with unsprayed foliage, and determined their mortality 48 hours later. The average mortality was 57, 39, 32, 9, and 8 percent with beetles captured 1, 2, 4, 48, and 72 hours, respectively, after spraying. The relatively high mortality of the beetles caught 1 hour after spraying was probably due to the direct contact of the spray with the beetles. Possibly many of the beetles captured later had not fed on the sprayed foliage. Van Leeuwen et al. (*1928*) estimated that the recommended lead arsenate-wheat flour spray killed about 30 percent of the beetles.

Coated Lead Arsenate

Beetles fed readily on foliage sprayed with basic lead arsenate and ferrous arsenate, compounds that are practically insoluble and nontoxic to them, but did little feeding on foliage sprayed with lead arsenate. Moore (*1922*) suggested that they tended to stop feeding on lead arsenate when they began to react to the compound, even before they had consumed a lethal dosage. The problem was to mask the lead arsenate in such a way that beetles would eat more of it.

Brinley (*1923*) produced a colloidal lead arsenate by precipitating the compound in the presence of gelatin. The beetles fed more readily on foliage sprayed with that product and more of them were killed than by the regular lead arsenate, but gelatin was considered an impractical coating material.

Various metallic soaps were investigated as coating agents for lead arsenate. Less repellent dusts were produced by grinding the arsenical with lead oleate or lead stearate (Moore *1922*), or by dissolving lead oleate or lead stearate in benzene or ethyl alcohol, mixing the solution with lead arsenate, and evaporating the solvent (Vander Meulen unpublished). These dusts were water repellent, adhered well to foliage, and were more palatable to the beetle, but few commercial growers in the area infested by the beetle were equipped to use a dust.

Vander Meulen (unpublished) devised a method of coating lead arsenate so that the product could be used as a spray. A metallic soap was precipitated in the presence of lead arsenate suspended in water. He prepared lead arsenate mixed with the aluminum, lead, and zinc soaps of cottonseed oil, fish oil, and linoleic, oleic, ricinoleic, and stearic acids. When the mixtures were diluted and sprayed, the metallic soaps spread over the lead arsenate particles as the deposits dried and formed a water-repellent coating. The mixtures of lead arsenate and lead oleate were the most promising.

Preliminary tests in 1928 and 1929 by Metzger (unpublished) and Van Leeuwen (unpublished) in apple, cherry, and peach orchards demonstrated that a 50:1 mixture of lead arsenate and lead oleate produced a higher initial deposit on foliage and the residue persisted longer than the 20:1 and 10:1 mixtures. As a result of these tests, the 50:1 mixture, referred to as "coated lead arsenate," was selected for further experimentation.

Van Leeuwen and Vander Meulen (*1926*) developed a procedure for producing coated lead arsenate commercially. The final product was a paste containing 45 percent solids and 55 percent water. Approximately 70,000 pounds of coated lead arsenate were used to control the beetle during 1927 (Van Leeuwen et al. *1928*). Larger amounts were used in subsequent years.

The coated lead arsenate was definitely more toxic to the beetle than the regular lead arsenate. In cage tests with coated lead arsenate at 8 pounds per 100 gallons of water and with regular lead arsenate at 6 pounds, in which correction was made for the mortality due to starvation, 46 percent of the beetles were killed by coated lead arsenate and only 5 percent by the uncoated arsenical within 48 hours (Van Leeuwen and Vander Meulen *1925*).

Coated lead arsenate applied at 8 pounds of the 45-percent paste per 100 gallons of water had about the same repellency to the beetle as the recommended lead arsenate-flour spray, but beetles alighting on the coated lead arsenate residue tended to remain longer and many of them fed until they had consumed a lethal dosage. Many dead beetles accumulated beneath trees, shrubs, and vines sprayed with coated lead arsenate, but only a few were found beneath plants sprayed with the uncoated arsenical. One application of coated lead arsenate protected the foliage for 6 to 8 weeks, but two applications of the lead arsenate-flour spray were required for that period. Coated lead arsenate was an important development in that it not only killed more beetles but it had better spreading and sticking qualities than any other lead arsenate spray used previously. (Van Leeuwen and Vander Meulen *1925;* Van Leeuwen et al. *1928*)

Van Leeuwen and Vander Meulen (*1926*) recommended 8 pounds of coated lead arsenate paste per 100 gallons of water to protect apple and cherry orchards, vineyards, and ornamental trees and shrubs, but they cautioned that the spray should not be applied to the fruit within 8 weeks of harvest. Van Leeuwen (*1929*) recommended that coated lead arsenate be used only to protect ornamental trees and shrubs and flowering plants, but later he (*1932a*) recommended it also for protection of young nonbearing apple trees, cherry trees after the fruit had been harvested, and young nonbearing grapes in commercial plantings.

Green Lead Arsenate

Some people objected to the white residue of lead arsenate on their ornamental trees and shrubs. To overcome this, Vander Meulen and Van Leeuwen (*1928*) prepared a green lead arsenate by precipitating chrome green among the lead arsenate particles suspended in water. The final product contained about 31 percent lead arsenate, 9 percent chrome green, and 60 percent water. When it was applied at 8 pounds of the paste per 100 gallons of water, the deposit was inconspicuous on foliage.

Vander Meulen and Van Leeuwen (*1928*) recommended mixing 8 pounds of the paste with 100 gallons of water and applying the spray when the beetles began to attack the ornamental plants and repeating it 3 to 4 weeks later.

Green lead arsenate was less repellent to the beetle than the regular lead arsenate. Van Leeuwen et al. (*1928*) and Van Leeuwen (*1932*) found that in comparison with unsprayed foliage the deposits of green and uncolored lead arsenate repelled 39 and 77 percent, respectively, of the beetles. The beetles fed no more readily on the colored than on the uncolored arsenical, but the greater beetle population on the plants sprayed with green lead arsenate caused more injury to these plants. Green lead arsenate never came into general use as a spray to control the beetle.

Adding Sugar to Lead Arsenate Sprays

For several years the beetle had been known to feed greedily on sugar solutions. In a preliminary laboratory experiment Vander Meulen (unpublished) attempted to administer a measured quantity of sirup to a beetle by inserting the tip of a microburette into its mouth. It was not possible to insert a tip sufficiently large to deliver the sirup accurately, and when administered in this manner the beetles tended to regurgitate. They did imbibe the sirup readily when drops were applied to the mouth parts by means of a small glass rod. A sirup containing 1 gram of lead arsenate in 100 ml. killed 76 percent of the beetles within 24 hours. A paris green-sirup mixture of this concentration killed 55 percent of the beetles in this period of time.

In field tests Van Leeuwen et al. (*1928*) and Metzger (unpublished) added 8 gallons of refined sugar sirup to 100 gallons of the lead arsenate-flour spray. The beetles tended to remain on the trees sprayed with that mixture and to gorge themselves on the foliage. The sprayed trees were practically defoliated and thousands of dead and moribund beetles accumulated on the ground beneath them. A higher mortality resulted with this spray than with any previous spray containing an inorganic stomach poison insecticide. Later Metzger (unpublished) found that adding the sirup made both the green and the coated lead arsenate very palatable to the beetles.

Smith (*1930*) considered the combination of lead arsenate and refined cane sugar sirup to be the most effective spray for killing large numbers of beetles. Adding the sugar practically destroyed the protective properties of the arsenical. The sugar did cause some burning on the foliage. It was apparent that sugar had no place in lead arsenate sprays designed to protect orchards and ornamental trees and shrubs from beetle attack. The lead arsenate-flour-sugar spray and the coated lead arsenate-sugar spray were recommended for plants of noneconomic importance to reduce the density of the beetle population in an area.

Paris Green and Its Homologs

Van Leeuwen (*1926*) observed that the beetle was attracted to large amounts of paris green on foliage. Later he (*1932*) found that trees sprayed with 18 pounds of paris green per 100 gallons of water attracted 44 percent more beetles than unsprayed trees in the vicinity. Since paris green has a slight odor of acetic acid, it was thought that the acid might be attracting the beetles. To demonstrate the attractiveness of acetic acid, he (*1926*) sprayed trees with water and with dilute acetic acid. Of the 320 beetles coming to the trees during the following 3½ hours, 8 percent came to the tree sprayed with water and 37, 23, and 32 percent, respectively, to the trees sprayed with 1:2,000, 1:1,000, and 1:250 acetic acid. The attractiveness of the dilute acetic acid lasted only a few hours, but the attractiveness of paris green did not decrease during a 10-day period.

Fleming and Baker (*1936*) studied paris green and several of its homologs under controlled conditions. The homologs were prepared according to the procedure outlined by Dearborn (*1935*). The sprayed plants and beetles were placed in special glass cages in a controlled atmosphere that stimulated feeding, following the procedure of Fleming (*1934*).

The injury by the sprays of paris green and its homologs to foliage increased progressively as the concentration was increased from 2 to 16 pounds per 100 gallons of water, and the feeding by the beetle on the sprayed foliage decreased from defoliation to slight with these changes in concentration. When applied at 8 pounds per 100 gallons, all these arsenites were less toxic to the beetle than lead arsenate at this concentration. The relative toxicity (percent) of the materials was a follows: Copper crotonoarsenite 81, paris green 70, copper palmitoarsenite 59, tung-oil green 56, cottonseed-oil green 47, copper lauroarsenite 39, soybean-oil green 23, rapeseed-oil green 17, copper oleoarsenite 16, and copper stearoarsenite 11. None of these arsenites appeared promising. Foliage sprayed with them was no more palatable to the beetle than that sprayed with lead arsenate, and the possibility of chemical injury to the foliage was greater.

Geraniol

To reduce appreciably the beetle population with residual sprays, it is necessary not only to have a palatable toxic residue on the foliage but to induce the beetles to come in large numbers to the sprayed plants. Geraniol was the only attractant used with sprays.

Adding Geraniol to Lead Arsenate Sprays

Richmond (*1927*) found that adding emulsified geraniol at 1:1,000 to the regular lead arsenate spray attracted large numbers of beetles to the plants shortly after they were sprayed, but the attractive odor dissipated rapidly and no more beetles were attracted. Since the residue of lead arsenate was not palatable, most of the beetles left the plants within a few hours.

Van Leeuwen et al. (*1928*) also mixed emulsified geraniol with the regular lead arsenate spray and applied it to a tree in an abandoned orchard. The geraniol excited the beetles to activity for about 20 minutes after spraying. Many beetles flew toward the sprayed tree, but some alighted on adjacent unsprayed trees. About an hour later more beetles were leaving the sprayed tree than were coming to it.

During 1929–32 the Department applied a spray containing 16 pounds of green lead arsenate, 8 gallons of cane sugar sirup, and 1 quart of emulsified geraniol per 100 gallons of water at weekly intervals to selected trees and shrubs to reduce the beetle populations at isolated infestations. It was difficult to evaluate the effectiveness of the operation because of the very light beetle populations.

In 1931 Rex (unpublished) applied a spray containing 9 pounds of green lead arsenate, 60 pounds of refined sugar sirup, 1½ pounds of emulsified geraniol, and 300 gallons of water to wild cherry and sassafras at six sites and to an abandoned orchard in a densely populated area in New Jersey. Within an hour after spraying, thousands of beetles were on the sprayed plants. By midafternoon the ground near the sprayed plants was covered with dead and dying beetles. Although beetles were plentiful in the vicinity, very few were attracted to the sprayed plants after that first day.

In 1933 Metzger (unpublished) added 1 quart of emulsified geraniol and 16 pounds of green lead arsenate or 9 pounds of coated lead arsenate to 100 gallons of water and found that the deposits on tree foliage were very attractive to the beetles only on the day the sprays were applied.

These experiments demonstrated that emulsified geraniol added to a lead arsenate spray dissipated too rapidly to be of much value.

Geraniol Dispenser With Lead Arsenate Sprays

To overcome the rapid dissipation of geraniol when applied in a spray, Van Leeuwen et al. (*1928*) hung sponges saturated with geraniol on selected trees throughout an apple orchard, which had been sprayed previously with lead arsenate and was well protected from beetle attack. A drip bottle was mounted above each sponge to keep it saturated with the attractant. The beetle population built up rapidly on the trees with the sponges and became so dense that masses of beetles were clustered on the fruit and foliage. There was extensive feeding on the foliage in spite of the unpalatability of the lead arsenate deposit to the beetles, and the entire crop on these trees was destroyed. Thousands of dead beetles accumulated on the ground beneath the trees with the sponges, but very few dead beetles were beneath the other trees in the orchard.

Metzger (unpublished) used a bottle-and-wick dispenser enclosed in a perforated metal cylinder to dispense geraniol in selected trees in an apple orchard that had been sprayed previously with green lead arsenate and coated lead arsenate, with and without cane sugar sirup. A second spray application containing sugar caused defoliation of the trees. The results were substantially the same as those obtained previously by Van Leeuwen et al. (*1928*), in that many more dead and moribund beetles were found beneath the trees with the dispensers than beneath the other trees.

Geraniol With Contact Sprays

It was not possible to attract and kill large numbers of beetles with a deposit of lead arsenate without causing serious injury to the fruit and foliage by the feeding of the beetles. It seemed more practical to attract the beetles to selected trees and kill them with a contact insecticide and thus avoid extensive feeding. Van Leeuwen (*1926a, 1926b*) developed a very effective contact insecticide containing sodium oleate and oleoresin of pyrethrum. With 5 gallons of the stock formulation mixed with 95 gallons of water, 95 percent of the beetles were dead within 48 hours on low-growing plants sprayed with a bucket pump and 98 percent on apple and peach trees sprayed with a power sprayer.

Van Leeuwen (unpublished) and Van Leeuwen et al. (*1928*) conducted a large-scale experiment with emulsified geraniol and the sodium oleate-oleoresin of pyrethrum spray to reduce the dense beetle population in a 3-square-mile area in southern New Jersey in 1926. Trees about 100 yards from other trees were selected for spraying. Four power sprayers, each with a crew of five men, operated in this area on days when the temperature was above 80° F., the relative humidity was between 40 and 70 percent, and the sun was shining—conditions favoring the flight of the beetle. The geraniol did not attract large numbers of beetles under other conditions. A selected tree was first sprayed lightly with the geraniol emulsion containing 1,000 ml. of geraniol, 40 grams of sodium oleate, and 4,000 ml. of water. Within a few minutes the beetle population on the tree built up rapidly. Then the contact insecticide was applied with two nozzles with spreaders in a coarse fan-shaped spray at a pressure of 500 pounds from the top of the tree downward so that few beetles were not thoroughly sprayed.

It was estimated that each application of the contact insecticide killed about 80 percent of the beetles on the selected trees. The ground beneath the sprayed trees was covered with dead beetles throughout the summer. Although millions of beetles were killed during the summer, it was difficult to evaluate the benefit of the operation because the beetle population did not appear to be substantially reduced in this area the following summer.

Anethole-Eugenol With Newer Insecticides

Although experimentation with a residual spray and an attractant was discontinued several years ago, such a combination could be used advantageously today in campaigns to eliminate isolated infestations and to reduce beetle populations at airports, where it is a problem to prevent beetles from entering a plane during the loading period. No additional experimentation is needed to use an anethole-eugenol dispenser in combination with malathion or DDT.

Large bottle-and-wick dispensers, filled with the 9:1 anethole-eugenol mixture and hung in selected trees throughout an isolated infestation or around an airport, would attract beetles as long as any bait remained in the wick.

Malathion, one of the safest insecticides, is a very effective contact insecticide to kill beetles on the selected trees. A spray containing 1 pint of a 50-percent concentrate or 2 pounds of a 25-percent wettable powder per 100 gallons of water, applied as a coarse drench, has killed many beetles during the spraying operation. Since the residual effectiveness of malathion is only 5 to 7 days, it would be necessary to spray at weekly intervals during the flight of the beetle (Fleming *1963*).

Probably the most practical method for killing beetles would be to spray the selected trees with DDT, using 2 pounds of a 50-percent wettable powder or 2 quarts of a 25-percent emulsifiable concentrate per 100 gallons of water. The spray is a good contact insecticide and the residual deposit appeared to be neither attractive nor repellent to the beetles. Beetles that walked or began to feed on the sprayed foliage soon became paralyzed and died. Unless there was excessive rain or much new growth, one application of DDT would be effective throughout the flight period of the beetle. (Fleming *1947, 1963*)

SUMMARY

There are three fields of investigation in the search for an attractant for the Japanese beetle (*Popillia japonica* Newman): The odoriferous constituents of plants preferred by the beetle and associated chemicals, fermentation products, and the lure of the female for male beetles.

Odoriferous Constituents of Plants and Other Chemicals.—Little was known about the odoriferous constituents of the many plants attacked by the beetle. Plants whose alcoholic extracts had an ethereal or fruity odor were most likely to be fed on extensively. Most of the preferred plants were reported to contain geraniol. Four of the preferred plants—apple, peach, rose, and sassafras—contained one or more of the following odoriferous chemicals, frequently combined with each other and with other constituents of the plants: Acetic acid, benzaldehyde, caproic acid, citral, citronellol, eugenol, geraniol, linalool, phenyl ethyl alcohol, and valeric acid.

The search for a beetle attractant was a trial-and-error process. Since the preliminary tests with olfactometers were unsatisfactory, the attractiveness of the various baits was determined in the field during 6 weeks in the summer when the beetle was flying. The first field evaluations were made by counting the number of beetles that came to open cans of sweetened bran containing various odoriferous materials. Although this method had several limitations, the most attractive essential oils appeared to be citronella, clove, lemongrass, palmarosa, sassafras, and tansy, and the most attractive chemicals were citral, citronellal, citronellol, eugenol, eugenol methyl ether, geraniol, and geranyl acetate.

A more precise evaluation was made by placing the experimental baits in traps and testing them in competition with a 10:1 technical geraniol-U.S.P. eugenol bait that was used as a standard. The beetle was attracted to a wide variety of unrelated odoriferous substances, probably because it is cosmopolitan in its choice of food. Mixtures of chemicals were almost invariably more attractive than was anticipated from the attractiveness of their components. The most attractive mixtures contained eugenol mixed with various combinations of anethole, caproic acid, geraniol, phenyl ethyl acetate, phenyl ethyl alcohol, phenyl ethyl butyrate, phenyl iso-valerate, and iso-valeric acid.

The attractiveness of the baits was modified by (1) the activity of the beetle as affected by temperature, relative humidity, and sunshine; (2) the purity of their components; (3) the rate of evaporation; (4) their decomposition on exposure to the weather; and (5) the nature and proportion of the ingredients in mixtures.

A 10:1 mixture of technical geraniol and U.S.P. eugenol was recommended as an attractant for the beetle from 1928 to 1944, when geraniol became unavailable. The eugenol was a standard product, but the geraniol was a complex mixture of several components with no standard specifications. Satisfactory specifications were developed for the highly refined grade of geraniol with at least 87 percent alcohol. However, the specifications when broadened to include some of the cheaper and equally attractive lower grades were less satisfactory because of difficulty in establishing the physical and chemical properties of these more complex, variable mixtures.

The attractiveness of the recommended geraniol-eugenol mixture was enhanced by increasing the eugenol content and by adding caproic acid, phenyl ethyl acetate, phenyl ethyl alcohol, phenyl ethyl butyrate, or phenyl iso-valerate, but for various reasons none of these mixtures, except one containing phenyl ethyl alcohol, were recommended as an attractant. The mixture containing this last substance was recommended only during 1936-39.

A 9:1 mixture of N.F. or technical anethole obtained from pine oil and U.S.P. eugenol has been recommended as an attractant since 1944. The natural anethole was less attractive than the synthetic product. Increasing the eugenol content tended to increase the attractiveness. Replacing half of the anethole with caproic acid more than doubled the attractiveness, but this mixture was not recommended.

Some mixtures of caproic acid, eugenol, and phenyl ethyl butyrate or phenyl iso-valerate and some mixtures of phenyl ethyl butyrate and eugenol were definitely more attractive than the geraniol-eugenol and the anethole-eugenol mixtures, but these mixtures had not been tested extensively enough to recommend them.

Fermented Baits.—Fermented apple juice, orange juice, malt sirup, and cane sugar sirup were more attractive to the beetle than the unfermented materials. Fermented baits did not seem desirable for general use.

Sex Attractant.—In nature the male beetle is strongly attracted to female beetles, but traps baited with virgin and field-collected female beetles did not attract either sex. Extracts of female beetles prepared with acetone, benzene, ethyl alcohol, and petroleum ether also did not attract beetles.

Ovipositional Chemotropism.—In a preliminary test a dilute alcoholic solution of allyl sulfide induced beetles to deposit eggs near the chemical.

Traps With Attractive Baits.—Electrical traps of 10,000 to 40,000 volts electrocuted many beetles attempting to fly between parallel wires, but these devices were not practical to use unattended and apparently did not appeal to the public.

A mechanical trap for densely populated areas and a survey trap for lightly populated areas are described. The best of these traps consisted of a funnel, a four-winged baffle mounted above and extending into the funnel, a bottle-and-wick dispenser for the bait mounted in the baffle, and a receptacle for holding captured beetles. A high luster yellow was the most effective color.

The best traps under favorable conditions captured about 75 percent of the beetles attracted to them. Most of the beetles captured in suburban areas were attracted to the traps from plants on the premises and adjacent properties, but in rural areas the beetles came largely from plants within about 400 feet of the traps. One trap per acre caught about 30 percent of the beetles in that area.

Traps have been of great value in determining the presence or absence of the beetle in areas not known to be infested. They were used extensively in New Jersey and Maryland in densely infested areas to reduce the beetle populations in those areas. In a few instances, traps in densely infested areas protected favored plants from severe beetle injury.

Attractive Sprays.—Lead arsenate is very toxic to the beetle, but most beetles ceased feeding on sprayed foliage before consuming a lethal dosage. The average mortality was about 30 percent. The lead arsenate deposit was made less repellent by coloring it green, and it was made more effective in killing beetles by coating the particles with lead oleate or by adding sugar to the spray. The beetles usually gorged themselves on the sprayed foliage when sugar was present and a high mortality resulted.

Adding emulsified geraniol to a residual spray such as lead arsenate was not satisfactory, because the attractant in the deposit on the plants was not effective for more than 1 day. It was practical to apply a spray of emulsified geraniol to concentrate beetles on selected trees and then kill them with a contact insecticide.

Beetles were attracted to trees sprayed with lead arsenate by hanging a bait dispenser in the trees.

Although experimentation with residual sprays and an attractant was discontinued several years ago, such a combination could be used advantageously today in campaigns to eliminate isolated infestations and to reduce beetle populations at airports. A large bottle-and-wick dispenser with the anethole-eugenol mixture as the attractant could be hung in selected trees sprayed with a residual insecticide.

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