STUDY OF FEEDING HABITS AND INVESTIGATING SOIL FUMIGATION AS A MEANS OF CONTROL FOR PECAN WEEVIL

STUDY OF FEEDING HABITS AND INVESTIGATING SOIL FUMIGATION AS A MEANS OF CONTROL FOR PECAN WEEVIL

By

KAY MING CHAU

Bachelor of Science

Lingnan University

Canton, China

1939

Submitted to the Department of Horticulture

Oklahoma Agricultural and Mechanical College

In Partial Fulfillment of the Requirements

for the Degree of

MASTER OF SCIENCE

1949

APPROVED BY:

Frank B. Cross
Chairman, Thesis Committee

Herman A. Hinrichs
Member of the Thesis Committee

Frank B. Cross
Head of the Department

D.C. McIntosh
Dean of the Graduate School

ACKNOWLEDGMENT

The author wishes to express sincerest appreciation to Dr. Frank B. Cross and Mr. Herman Hinrichs, who so willingly gave their time and interest in connection with the research study.

Grateful acknowledgment is also expressed for the assistance rendered by Mr. Fred LeCrone and other members of the Horticulture Department.

TABLE OF CONTENTS

INTRODUCTION

Pecans are a promising crop in the southern and south central part of the United States. This area is the world's largest native pecan belt. Texas, Oklahoma, Alabama, Mississippi, Georgia, Louisiana and Florida are the important producing states within this region. The State of Oklahoma, the second largest native pecan producing center, alone produced 28,000,000 pounds during 1947.

According to chemical analysis pecan kernels contain 75 per cent oil, the richest of all nut fruits, 10 per cent protein, 12 per cent total carbohydrates, with but very little water and fiber (9). Due to its highly nutritious content and delicious flavor, the pecan is an important horticultural commodity. To process native nuts, because of the increased demand for pecan kernels during recent years, an increased number of pecan shelling plants have been set up in the State.

With the development of the pecan business into a specialized industry there arises the problem of intensified insect damage to the crop. Generally it requires 240 to 250 days for the southern varieties of pecans to mature nuts, and from 180 to 200 days for the northern ones. This long period of nut development exposes the crop to attack by many insects. Insects originally found only in local pecan areas may multiply so rapidly as to spread to attack new areas. Others may have transferred to pecan trees from nearby hosts, such as hickories.

The pecan weevil Curculio caryae (Horn) is one of the most important pecan insect pests in Oklahoma. Growers' reports of heavy losses due to weevil devastation are not uncommon. The insect is very tenacious after having become established in a certain locality. It causes increasing losses to the crop year after year. Injury from the weevil includes damage by both the larva and the adult. Each female deposits eggs on from 10 to 30 nuts. When larvae hatch from these eggs they consume the kernel of the nut.

The aim and scope of this study includes three main phases: (1) the observation of habits and feeding activities of the weevil; (2) determination of soil penetration and movement of the larva and (3) soil fumigation. No effective method of control has yet been recommended for practical use except D.D.T. spray for the trees. A study of soil fumigation possibilities offers opportunity of devising additional control measures. A vulnerable stage in the life cycle of the weevil is the long period spent in the soil as a larva.

REVIEW OF LITERATURE

It is almost inevitable that wherever pecan trees are grown pecan weevil will be added to the category of important insect pests. Originally the pecan was treated as a wild-grown nut. It began as a cultivated horticultural crop only during the last century. In comparatively recent years it has assumed a prominent place in the commercial nut market. Losses due to insect damage are now realized by growers and an urgent need for effective control is apparent.

Pecan varieties differ rather widely in susceptibility to weevil injury. Moznette (16) points out that early filling varieties suffer most from infestation. Weevils will find those early developing nuts for laying eggs. It has been noted by Swingle (29) that there has been a 40 per cent loss of a crop from Schley pecan in central Alabama over a six year period. He also reported that male and female weevils feed on immature nuts during July and August with the result that injured nuts fall prematurely. During one year, over 80 per cent of the entire Schley (29) was reported lost in this way. Late varieties (16) have suffered far less damage than early varieties.

An adult pecan weevil is greyish brown in color. It has a characteristic beak which is longer in the female than in the male. This insect belongs to the Family Curculionidae of the Order Coleoptera which possess chewing type of mouth parts and undergo complete metamorphosis (13). In Oklahoma, adult weevils are active in trees from July to October. Females drill holes into the nuts with their beaks and then lay eggs in separate pockets of the kernel. It has been found that egg deposition will not start until the kernels begin to harden. Both the beak and the ovipositor of the female are about the same length which, if the latter is extended, is about 11 millimeters long. The ovipositor is retracted when it is not in use, forming a double-wall tube within the body.

The larvae appear as white grubs which develop and mature in the nut. Then they bore a hole through the shell to come out and enter the ground. The larvae are legless and have small reddish brown heads. They begin to emerge from the nuts in the latter part of September and continue into December and January. In Georgia a majority of them enter the soil during the month of October (16). The depth of penetration depends upon the condition of the soil. Usually one will find them deeper in soil that has previously been cultivated. Pupation takes place in the soil usually the second year about 18 months after entering the ground and then the adult forces its way out the following summer. Weevils seem to appear in large broods every other year.

Weevils injure and damage the nuts in two ways. First, in feeding they puncture the nuts prior to the kernel formation stage. The injured nuts become shriveled and discolored, resulting in an early dropping. Second, they lay eggs in the nuts after the kernels are formed. Larvae hatched from eggs devour the kernel meat content of the nuts.

Experiments for the control of larvae by means of cultural methods have been tested by Bissell (1), but the result was ineffective as surface cultivation and did not prevent burrowing of larvae into the soil. He also observed that some environmental factors may influence the burrowing of larvae in the soil. Conditions such as sufficient plasticity of the soil to hold the shape of burrow or sufficient friability to allow the working of the larva's muscular power may facilitate the larva in burrowing. Rains help the larva to burrow by softening the ground and by reducing the surface temperature of soil. Larvae prefer shaded areas under the trees for burrowing. Sunshine and strong winds are extremely detrimental to them.

In the southeastern states, Moznette has found D.D.T. a fairly satisfactory control for pecan weevil (14 and 15). Three applications of a spray using 8 pounds of 50 per cent wettable D.D.T. in 100 gallons of water resulted in an increase in yield. He also reported that two applications of D.D.T. at the rate of 6 pounds 50 per cent wettable powder to 100 gallons of water reduced the infestation to 1 per cent.

In 1930, Kislanko (11) stated that fumigating pecan nuts with carbon disulfide was probably the best method of control, while in 1922, Porter (19) reported emulsions of carbon disulfide for the control of the insect in the soil.

Stucky and Kyle (28) suggested a practical method of control was to turn hogs into an orchard to clean up all the weevil-infested pecans falling on the ground. They also used carbon disulfide for the fumigation of larva infested nuts during storage.

It is recommended (16) that six jarrings at intervals during the active season of pecan weevils will control them satisfactorily. It is also advisable that weevil-infested nuts should be harvested as early as possible.

Phillips and Cole (18) did not mention pecan weevil among several others as the important insect pests of pecan trees in Florida. Consequently, in some places pecan weevil may not be regarded as so serious an insect as to cause significant damage.

In recent years a method of soil fumigation has been adopted to control harmful soil organisms, but experiments are concerned largely with pests other than the pecan weevil.

For the control of root-knot nematodes, Newhall (17) used Propylene dichloride at the rate of 12.5 mililliter per dosage of one injection per 10 inch square spacing in the soil. A fairly good result was obtained. Snapp (22 and 23) reported using Propylene dichloride for the control of peach tree borer. He used half pint of 10 per cent emulsion for a 3 to 4 year old tree, obtaining good results. The diluted emulsion was poured upon the soil around the trunk of the tree. Though Propylene dichloride is a compound made by adding chlorine to propylene, there is no harmful result in working with it unless it is breathed at very high concentrations.

The Dow Chemical Company Laboratory (5) has demonstrated Ethylene Dibromide as an effective soil fumigant. The minimum dosage in using Dowfume W-40 for an orchard is 20 gallons per acre for the control of nematodes and other soil pests. Dowfume W-10 is also recommended for the effective control of root-knot nematode at the rate of 30 gallons per acre.

Benzene hexachloride has been recommended (8) for the effective control of wireworms, white grubs and other soil insects. One pound of the gamma isomer per acre is suggested.

Recently, C. B. Nickels[1] has conducted extensive tests at the Pecan Field Station, Brownwood, Texas, with Dichloroethyl ether for the control of pecan weevil. The result has been reported ineffective.

Frear (7) recommended dichloroethyl ether as a successful fumigant for greenhouse use, although such plants as roses, carnations and peaches might be easily injured.

For the control of curculio in peach trees, Snapp reported several experiments on the use of dichloroethyl ether at the rate of 1/3 fluid ounce per gallon of water for every 6 square yards of soil. The result was a good control for plum curculio that were attacking peaches. It was applied in the form of an emulsion with fish-oil soap and no injury to vegetation or foliage was observed.

Newhall used dichloroethyl ether at the dosage of 2.5 mililliters per injection on 10 inch centers obtaining good results (17) for the control of

---

[1]Mentioned in his letter to the author, June 12, 1948.

nematodes. When he increased the dosage to 5 milliliters per injection it proved toxic to plant growth; but when 1/3 fluid ounce per one gallon solution for one square yard of soil was used, the result was very toxic to the larvae with no damage to vegetation.

Chlordane, a new insecticide was reported in literature by Kearns, Ingle and Metcalf (10) in 1945. Chlordane is more toxic than D.D.T. in many instances and compares favorably in toxicity to the pure gamma isomer of hexachlorocyclohexane to a number of species of insects. Chlordane in general exhibits a wide range of effectiveness against insects. All evidence indicates that it has contact, stomach poison, and fumigant action. It has proven quite effective both in the laboratory and under field conditions against such pests as beetles, earwigs, ticks, and others.

Powell, Chandler, and Kelley (20) jointly reported that Chlordane is a good control for plum curculio and grasshoppers. A spray applied at the rate of one pound per acre can prevent new invasions of grasshoppers from adjoining fields for at least two weeks.

METHODS AND MATERIALS

Feeding Habits

Pecan weevils were collected from trees by jarring. From the middle of September to the latter part of October, 1947, three 20 year old trees in Adams' Pecan Grove near Stillwater were jarred every other morning for the purpose of observing insect activities. A large picking sheet, 24 x 24 feet, was placed under the spread of the branches. Each large branch of the tree was jarred several times causing weevils to drop on the sheet. They were found to have the habit of "playing possum" and they seemed to be least active in the early part of the day. The number of weevils collected began to decline on October 13, 1947. The first larva was observed to emerge from the mature nuts on October 17. A fewer number of males than females was collected near the end of the season.

In the laboratory, male and female weevils were kept separately in insect jars for the purpose of observing feeding habits and egg laying. An insect jar, 3 inches in diameter and 10 inches high, was equipped with a screen wire lid to provide air circulation for the weevils. A layer of sand $2\frac{1}{2}$ inches deep was placed in the bottom of the jar, a piece of white paper was placed upon the sand, and sufficient water was added to keep the sand in a moist condition. Next, a twig consisting of pecans and leaves was introduced into the jar so as to provide as natural an environment as possible for the confinement of weevils. The major activities of the pecan weevil involved were those of feeding and egg laying. At the slightest disturbance these activities were discontinued.

The male weevil drilled only half the length of its shorter beak into the pecan for feeding. The female was observed drilling into the kernel of the nut with her entire beak (Plate 2). After completing a puncture, she withdrew the beak and turned around to insert the ovipositor in the same hole

Plate 1. A Pecan Weevil in the Act of Drilling a Hole

Plate 2. A Pecan Weevil Drilling its Beak Full Length Into the Kernel

to lay eggs (Plate 3). The leg prints of the female weevil showed that she formed a circle around the puncture as she turned round and round in making the hole (Plates 1 and 4).

Weevil-stung nuts were collected and stored for larva observation. When these nuts were cut open they were found to contain from 2 to 4 larvae (Plate 5). This observation was carried out at weekly intervals. Smaller larvae were found in the beginning few weeks while larger ones were found gradually as time progressed. After completing its growth, during which it almost completely destroyed the kernel, the matured larva bored a circular hole 1/8 of an inch in diameter through the hard shell. By contraction and extension movements of the body each larva squeezed out of the nut. It was not uncommon that all larvae in one nut came out successively from the same hole. Matured larvae were rather plump and yellow in color and were generally from 3/8 to 1/2 inch long. In general, eggs required a week to hatch and larvae became fully grown in a month's time.

The mouth parts of the weevil were observed under the microscope by examining the tip of the beak. Two sharp teeth were found which served as the mechanism for drilling the holes and for feeding purposes.

Larva: Rate of Penetration into the Soil

The experiment was carried out in the latter part of November, 1947, when larvae started coming out of pecans and were active in penetrating the soil. A large number of weevil-infested nuts were first collected and then placed in a specially made wooden tray (Plate 6). This tray was 1½ feet wide, 3 feet long and 8 inches in height with a screen wire bottom so that the larvae that came out were received in another box underneath. The lower box was filled with 6 inches of moist, sandy soil for keeping the larvae temporarily.

Three phases of the larva's burrowing movements were studied. First, larvae were released on the surface of the soil to observe the time each one

Plate 3. A Female Weevil Laying Eggs

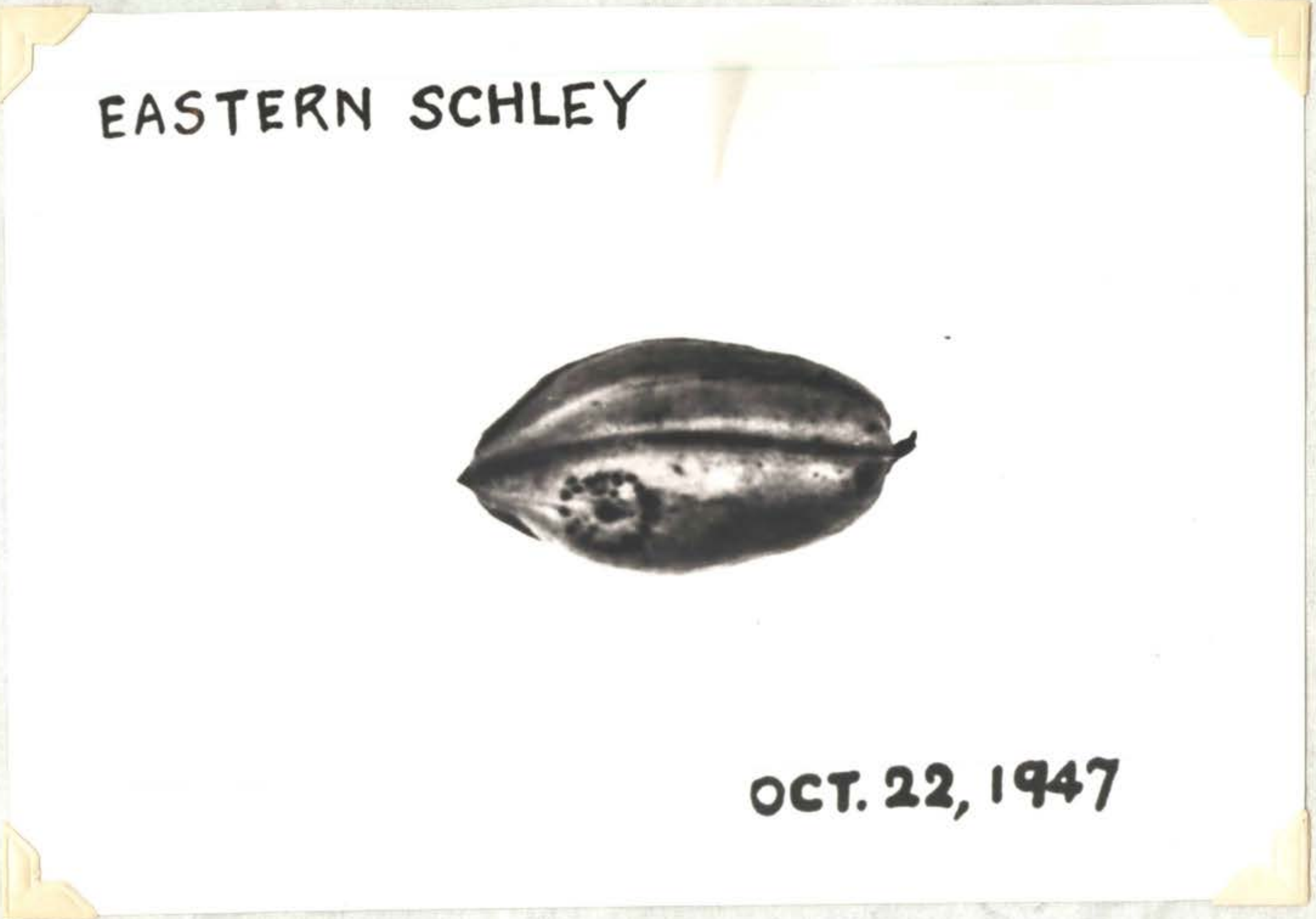

Plate 4. A Characteristic Puncture and a Surrounding Circle Made by a Weevil was Shown near the Terminal End of the Nut

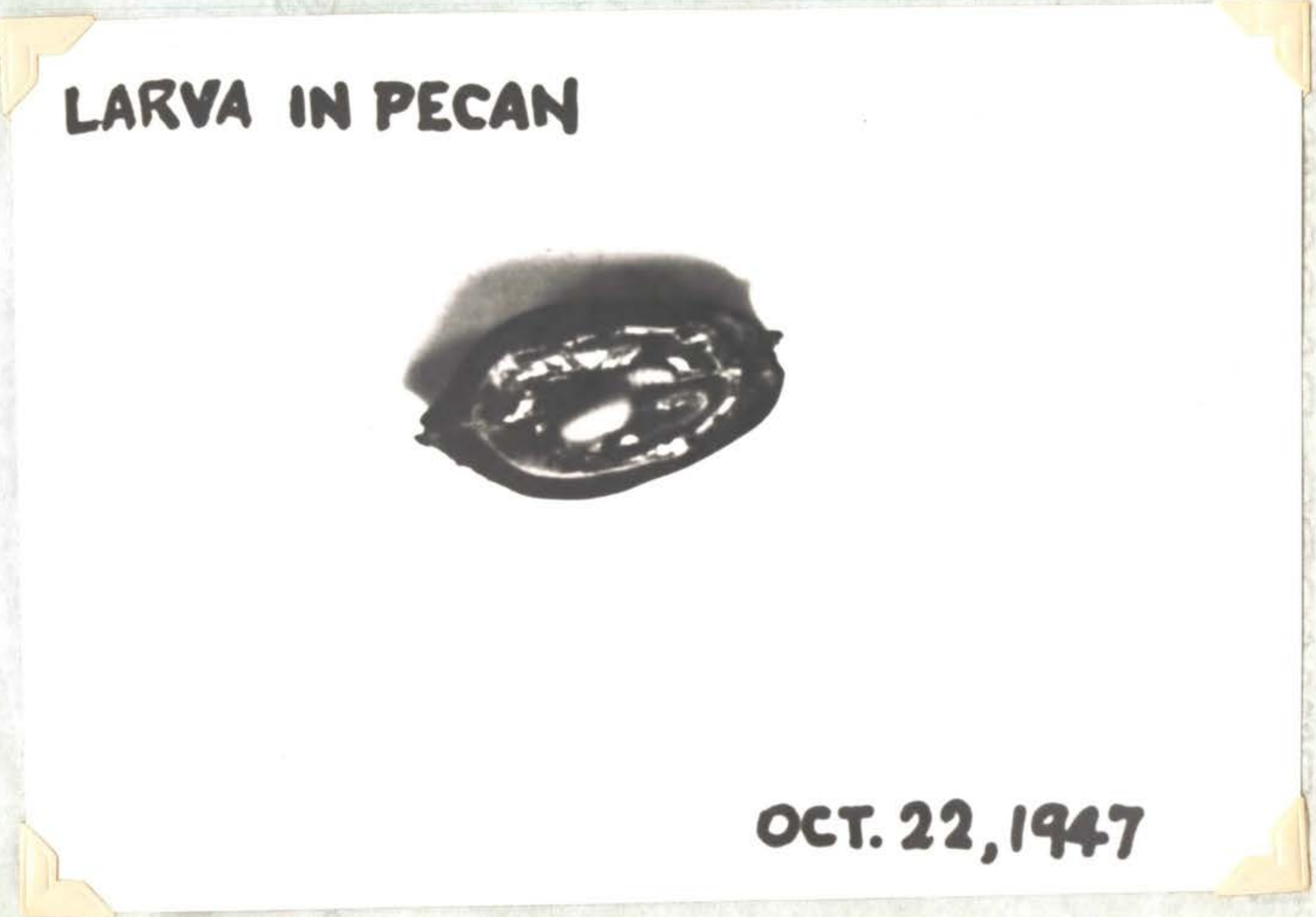

Plate 5. A Larva Feeding upon the Kernel

Plate 6. Method of Collecting Larvae from Pecans.

Upper Box has a Screen Wire Bottom

The Lower Box is Directly Underneath to Catch the Larvae required to burrow until entirely disappearing into the soil. A stop-watch was used for recording the time.

Second, larvae were allowed to penetrate in both sandy and clay loam soil for certain periods of time. Then they were dug from the soil to note their depth of penetration.

Third, larvae were introduced into the soil by confining them in a small circular area marked on the soil surface. After certain periods of time they were dug so as to measure the distances they deviated from the center point to investigate how far they moved horizontally in the soil. A spade, a trowel and a ruler were used for this experiment.

Two, five and ten-hour tests.

A total of 50 larvae were introduced to each of the sandy and clay loam soils for the observation of their penetration ability. A plot of one square foot was marked off on the surface of the soil and 15 larvae were allowed to burrow for the first trial. A second lot of 15 larvae were introduced into another plot. Then a third lot of 20 was introduced in the third plot, making up the total number of 50 larvae for the experiment. At the end of 2 hours the soils of each of the 3 plots were carefully dug out by slicing off the soil in thin layers with a flat-blade spade to a depth of 6 inches. When a larva was located, its depth of penetration was measured with a ruler from the spot located perpendicularly to the level of the soil surface.

A total of 50 larvae were also used for the 5 hour and 10 hour tests in both sandy and clay loam soils respectively, making a grand total of 300 larvae for the penetration tests of the 3 varied periods of time. The results appear in Table 1.

One-day, two-day, one-week and two-week tests.

Relatively longer periods of time from one day to two weeks were allowed for testing the penetration of larvae. To the first plot of soil one foot square 25 larvae were introduced, the same number for the second plot, while 50 were placed in the third plot making a total of 100 larvae for each trial in both sandy loam and clay loam soils.

A total of 100 larvae were also used for each of the trials of different lengths of time; namely, one day, two days, one week and two weeks in both sandy and clay loam soils. In digging for the larvae, the soil was excavated to a depth of 10 inches. The depth of penetration of each individual larva was measured. The following Table 2 indicates the results.

Twenty-week and twenty-eight-week tests.

Maximum depth penetration data were procured by noting the level at which larvae were found in the fumigation plots. For the fall fumigation, larvae were introduced upon the soil on November 12, 1947, and were dug on March 31, 1948 (a period of 20 weeks). Both live and dead larvae were found in the soil during the digging process and their depths of penetration were measured and recorded. A total of 899 larvae were located out of the original 1,260 burrowing in the 12 separate pens at the beginning of the experiment. The soil was of sandy loam type in the pecan grove and was excavated to a depth of one foot.

For the spring fumigation plots, the larvae were introduced on November 15, 1947 and left until May 29, 1948 throughout a period of 28 weeks. Out of the same original total of larvae introduced, only 664 were found. The penetration depths in the soil of both living and dead larvae were measured and recorded. This probably indicates maximum depths of penetration for this particular type of soil.

Testing the time larva required to burrow from soil surface into the ground.

Fresh and active larvae were released on the surface of both sandy and clay loam soils to observe their act of burrowing. A stop-watch was used to keep the time each individual larva required to burrow or disappear into the soil. A total of 50 larvae were tried one after the other. The range of burrowing time required by the larva is shown in Table 5.

Horizontal movement of larva in soil.

Fifty lively larvae were placed in a small confined area on the surface of both sandy and clay loam soils. An iron rod was thrust one foot deep vertically into the soil exactly through the center spot of the area as a reference point for horizontal measurements. Four lots of 50 larvae each were dug after one day, two day, one week and two week intervals. During digging, when a larva was located, the distance it deviated from the central rod was measured horizontally. Data are shown in Table 6.

Soil Fumigation Tests

Twenty-four pens, each 3 x 3 feet, were built under walnut trees in the College pecan grove to hold larvae for fumigation tests. Twelve pens were used for the fall test and twelve for the spring test. The pens were made of 1 x 6 inch boards set edgewise five inches deep in the soil (Plate 7). A space of 3 feet was left between adjacent pens. After larvae were introduced into the pens and during the whole period of fumigation, the soil temperature at a depth of 6 inches was recorded by charts. A metal rod connected by a wire to the temperature recorder was buried 6 inches deep in the soil. The temperature charts were renewed once every week. The average weekly soil temperature was calculated from the temperature curve on the charts by means of a planimeter using the following formula: Base line $+ \left(\frac{\text{Area under curve}}{\text{Total area}} \times \text{range}\right)$.

A hand injector was used for applying the chemicals. It consisted of a

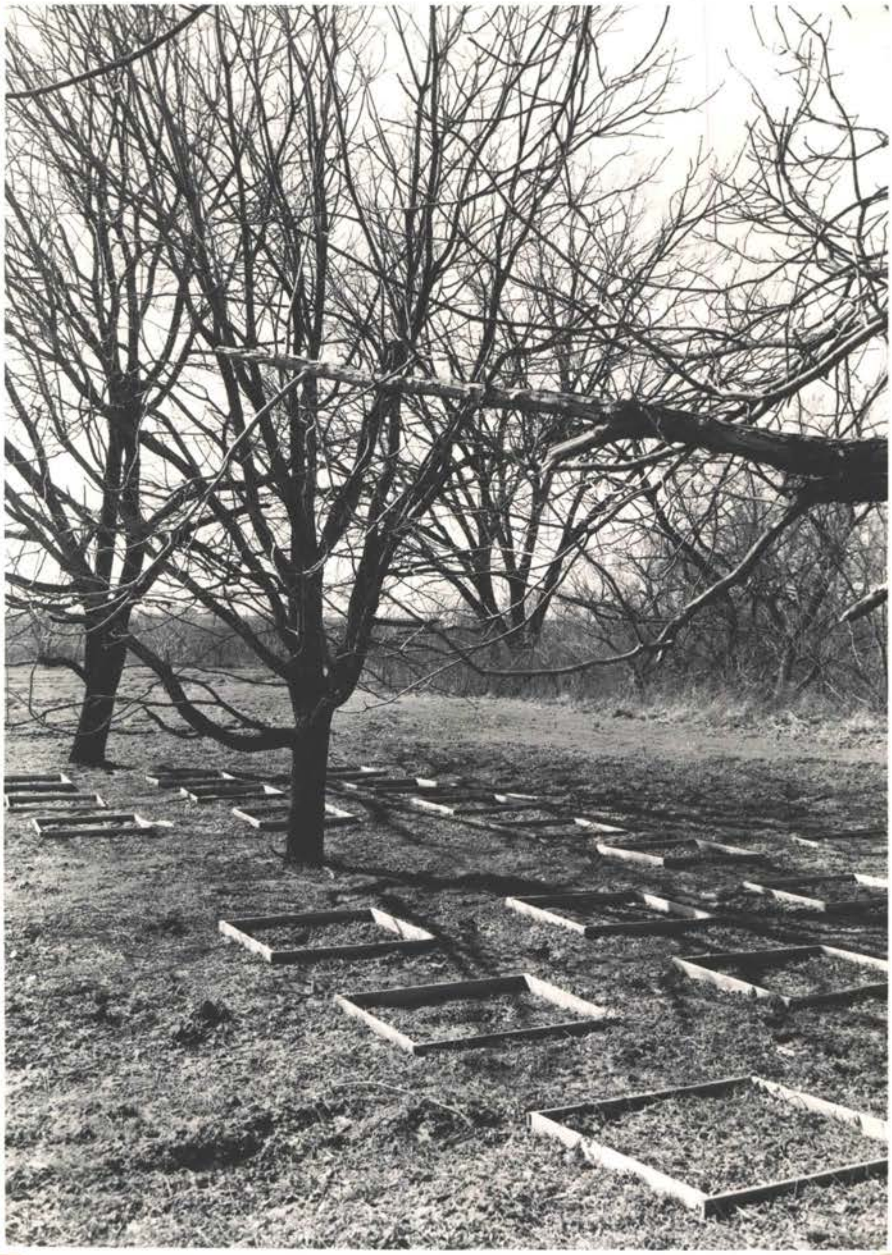

Plate 7. Arrangement of Pens, Spacing 3 feet Apart,

Under Walnut Trees.

Each Pen, 3 x 3 feet, Contained 105 Larvae force feed pump in the upper part of the rod which accurately measured and forcibly ejected the liquid with one stroke (Plate 8). The type of injector used in this experiment could be calibrated from 1 to 60 milliliters at a single stroke. Pens were dug to a depth of 1 foot to search for the remaining living or dead larvae after treatment with chemical for a certain period of time. A shovel and a ruler were used.

Chemicals used.

The 5 kinds of chemicals used for fumigation were Propylene dichloride, Ethylene dibromide, Benzene hexachloride, Dichloroethyl ether and Chlordane.

Propylene dichloride ($CH_3CHCLCH_2CL$) is a clear, colorless liquid made by adding chlorine to propylene. It has a boiling point at 95.4°C, a freezing point at -70°C, and a specific gravity of 1.16. It is inflammable, very soluble in alcohol or ether, and fairly stable in the presence of water.

Propylene dichloride stock emulsion was prepared by stirring 8 parts by volume of the compound into 1 part of potash fish-oil soap. The emulsion should be prepared in a well ventilated place or out of doors to avoid prolonged breathing of its vapor. The stock solution was diluted with water before use. After the emulsion had been applied, sufficient soil was used to cover the injection holes.

Ethylene dibromide is a non-corrosive, but inflammable chemical with a pleasant odor. Dowfume W-40, which contains approximately 40 per cent of Ethylene dibromide by weight, is prepared by dissolving ethylene dibromide in a hydrocarbon solvent. It has a boiling point of 131.7°C, a specific gravity of 2.17 and has a long period of persistance in soil. But it vaporizes rapidly after being injected in soil, resulting in a thorough fumigation of the soil to a depth of 14 to 16 inches. A "sealing in" is necessary immediately after fumigation. The cost of Dowfume W-40 is $2.25 per gallon.

Plate 8. A Soil Injector in Operation

Benzene hexachloride is a new organic insecticide, containing gamma isomer of Benzene hexachloride as the active ingredient and other isomers of Benzene hexachloride. Gamtox Wettable possesses 6 per cent gamma isomer of Benzene hexachloride, 40 per cent other isomers and 50 per cent technical Benzene hexachloride. It can be applied as a spray, a dust or in a solution form for injection in soil, using enough water to assure uniform distribution. This material costs 60 cents per pound.

Dichloroethyl ether ($C_4H_8Cl_2O$) is a colorless liquid with a chloroform like odor. It is extremely resistant to hydrolysis and is soluble in all oils and organic solvents. It has a specific gravity of 1.22 and a boiling point of 178.5°C. This high boiling point has the advantage of allowing the fumigating process to proceed over a considerable length of time. This chemical is not very volatile and its vapor is about $5\frac{1}{2}$ times as heavy as air.

A stock solution is prepared by first stirring 9 parts by volume of Dichloroethyl ether into 1 part of potash fish-oil soap. The ether must be added slowly and each portion completely worked into the soap before another is added. When the fish-oil soap and dichloroethyl ether have been thoroughly emulsified, water is added with constant stirring until the emulsion measures twice the volume of dichloroethyl ether used. This results in a stock emulsion containing 50 per cent of dichloroethyl ether. The stock emulsion is diluted with water before use, depending on the dilution required. This chemical weighs 10.2 pounds per gallon and it costs 17 cents a pound.

Chlordane ($C_{10}H_6Cl_8$) is a chlorinated hydrocarbon compound, soluble in deoderized kerosenes and other organic solvents, but insoluble in water. Chlordane should be formulated with diluents having acidic properties. It is viscous, nearly odorless and has a boiling point at 175°C. The 40 per cent Wettable Chlordane powder retails at $1.15 per pound.

The Fall Application.

The arrangement of the 12 pens for the fall fumigation is shown in the following diagram:

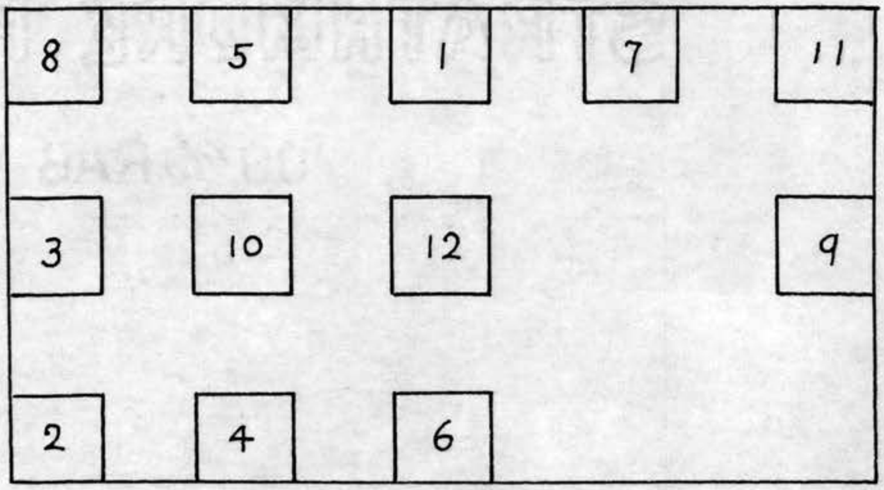

Figure 1. Twelve Pens Built under Walnut Tree for the Fall Fumigation

Each pen was numbered as designated by a randomised system. A total of 105 larvae were introduced with a spoon to each pen. Larvae were spread evenly on the soil surface in order to attain a fairly even distribution in the soil after their penetration. The pens were treated with chemicals seven weeks after the larvae were in the soil.

All pens were chemically treated except Pen No. 12, which was used for a check plot. Pen No. 1 and Pen No. 2 were treated with Propylene dichloride applied at the rate of 2 fluid ounces and 4 fluid ounces per square yard respectively. Pen No. 1 received $1\frac{1}{4}$ pints and Pen No. 2 received $2\frac{1}{2}$ pints of the 10 per cent emulsion of Propylene dichloride.

Pen No. 3 and Pen No. 4 were treated with Ethylene dibromide (using Dowfume W-40) applied at the rates of 20 and 40 gallons per acre respectively.

Pen No. 5 and Pen No. 6 were treated by spraying the surface of the soil with Benzene hexachloride at 20 pounds and 30 pounds per acre respectively. For Pen No. 5, two grams of Benzene hexachloride were diluted in two pints of water, and for Pen No. 6 three grams were diluted in the same quantity of water.

The surface of Pen No. 7 was dusted with Benzene hexachloride at the rate of 20 pounds per acre. Talc was used to increase the volume of the dust to obtain a more uniform application.

Pen No. 8 and Pen No. 9 were treated with Dichloroethyl ether at 20 gallons and 40 gallons per acre respectively.

Pen No. 10 was treated by spraying the surface of the soil with Chlordane at the rate of 6 pounds per acre. Chlordane was diluted with enough water for adequate distribution.

Pen No. 11 was dusted with Chlordane at 20 pounds per acre. Sufficient talc was used to dilute the chlordane to get a uniform application on the soil surface.

All the fumigants, except Benzene hexachloride and Chlordane, were applied by the Spot Injection Method. In the treatments with Ethylene dibromide and Dichloroethyl ether the pens were marked off into 12 inch squares on the soil surface of the plot, thus making 14 injection points to each pen.

Thirty injection points were made in each of the pens treated with Propylene dichloride. The injector punched holes 6 inches deep into the soil (Plates 8 and 9). Holes were covered up with soil immediately after fumigation. This fall application work was completed on December 30, 1947, and results were checked on March 31, 1948, by digging and counting the live and dead larvae in the soil of each of the pens. The whole period of time took 13 weeks from fumigation until digging.

The Spring Application.

The arrangement of the 12 pens for the spring fumigation is shown in the following diagram:

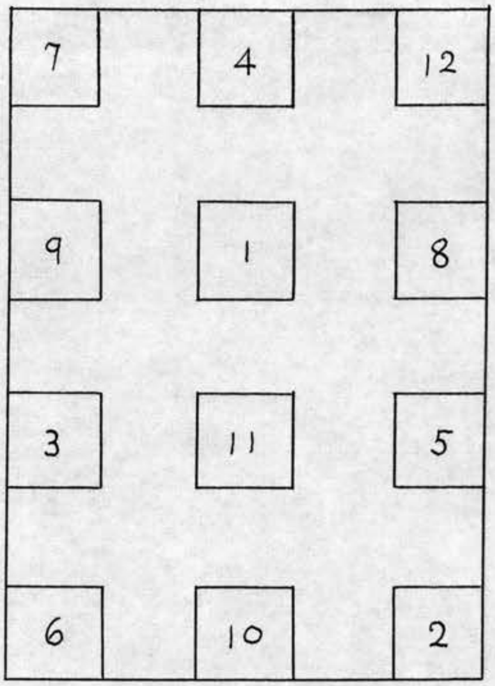

Figure 2. Arrangement of 12 Pens for the Spring Fumigation

The number of each pen was designated at random. This second test using the same fumigants was applied April 24, 1948, thus allowing a period of five months for the larvae to establish themselves in the pens. The Spot Injection method was used in all the treatments in this test. Each plot was marked off into 10 inch squares with a 3 inch spacing around the border of each pen. A total of 16 injection holes were made in each. (See Figure 3).

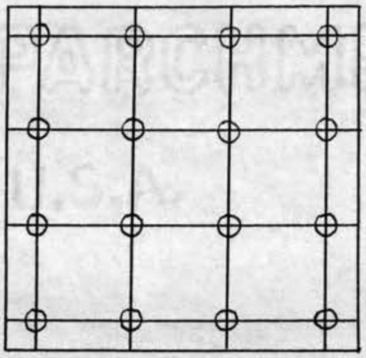

Figure 3. 16 Holes in each Pen by the Spot Injection Method

Plate 9. Injecting Propylene Dichloride

Six Inches Deep into the Soil

Pen No. 1 and Pen No. 2 were treated with Propylene dichloride at the rates of 8 fluid ounces and 4 fluid ounces per square yard respectively.

Pen No. 3 and Pen No. 4 were treated with Ethylene dibromide at the rates of 20 gallons per acre for the former pen and 40 gallons for the latter.

Pen No. 5 and Pen No. 6 were treated by injection with Benzene hexachloride at the rates of 20 pounds and 30 pounds per acre respectively. The former was accordingly treated with 1.87 grams of the chemical by mixing with water to $1\frac{1}{4}$ pints before use, while the latter had 2.8 grams in $2\frac{1}{2}$ pints of water.

Pen No. 7 and Pen No. 8 were each treated with Dichloroethyl ether; the former using $1\frac{1}{4}$ pints of the 5 per cent emulsion at the rate of 1 fluid ounce per square yard and the latter using $1\frac{1}{4}$ pints of the 7.5 per cent emulsion at the rate of $1\frac{1}{2}$ fluid ounces per square yard.

Pen No. 9 and Pen No. 10 were treated by injection with Chlordane at the rates of 6 pounds and 9 pounds per acre respectively. Chlordane was diluted with water to $1\frac{1}{4}$ pints in each case.

Pen No. 11 and Pen No. 12 were used as check plots. These untreated plots were probed 16 times just the same as the other plots were injected. The mechanical injury made by the injector would be the same in the check pens as well as in the treated pens.

All the pens were dug during the end of May, 1948, five weeks after treatment. The method of digging was to approach from the outside of the pen. An area 1 x 3 feet outside of, but adjacent to, the plot was dug first (Plates 10 and 11) to reach a depth of 1 foot in the soil. Then the board was removed to start working the soil inside the pen (Plate 12). A spade of a flat-bladed type was used and the soil was shaved off perpendicularly downwards. As thin slices of soil came out, larvae were easily located (Plate 13). A ruler was used to determine the depth of penetration whenever a larva was found. The number of both living and dead larvae was recorded (Plates 14, 15, and 16). Soil was constantly removed from the bottom after each shaving process to retain the depth of the excavation uniformly one foot throughout (Plates 17 and 18). A screen was used to sift the soil to search for any larva that might be passed unnoticed in a lump of soil. Soil was sifted onto a canvas sheet laid on the ground (Plate 19).

Actual tests of the effect of chemicals on pecan trees.

Twenty pecan trees were selected for testing the effect of the chemicals used in this experiment on the trees themselves. The same rates of each chemical as those applied in the spring fumigation were used. Propylene dichloride was applied at the rates of 2 and 4 fluid ounces per square yard, Ethylene dibromide at 20 and 40 gallons per acre, Benzene hexachloride at 20 and 30 pounds per acre, Dichloroethyl ether at 1 and $1\frac{1}{2}$ fluid ounces per square yard, and Chlordane at 6 and 9 pounds per acre respectively. Each of the above 10 treatments was applied around two trees. The soil around each tree was injected at 10 inch intervals starting from the base of the tree and extending outward from the trunk to the full length of the branches. Trees were treated on May 26, 1948, when new growth and young leaves were vigorously developing. Observations were made once every week after fumigation to check whether the chemicals would have any possible effect on plant growth (Plate 22).

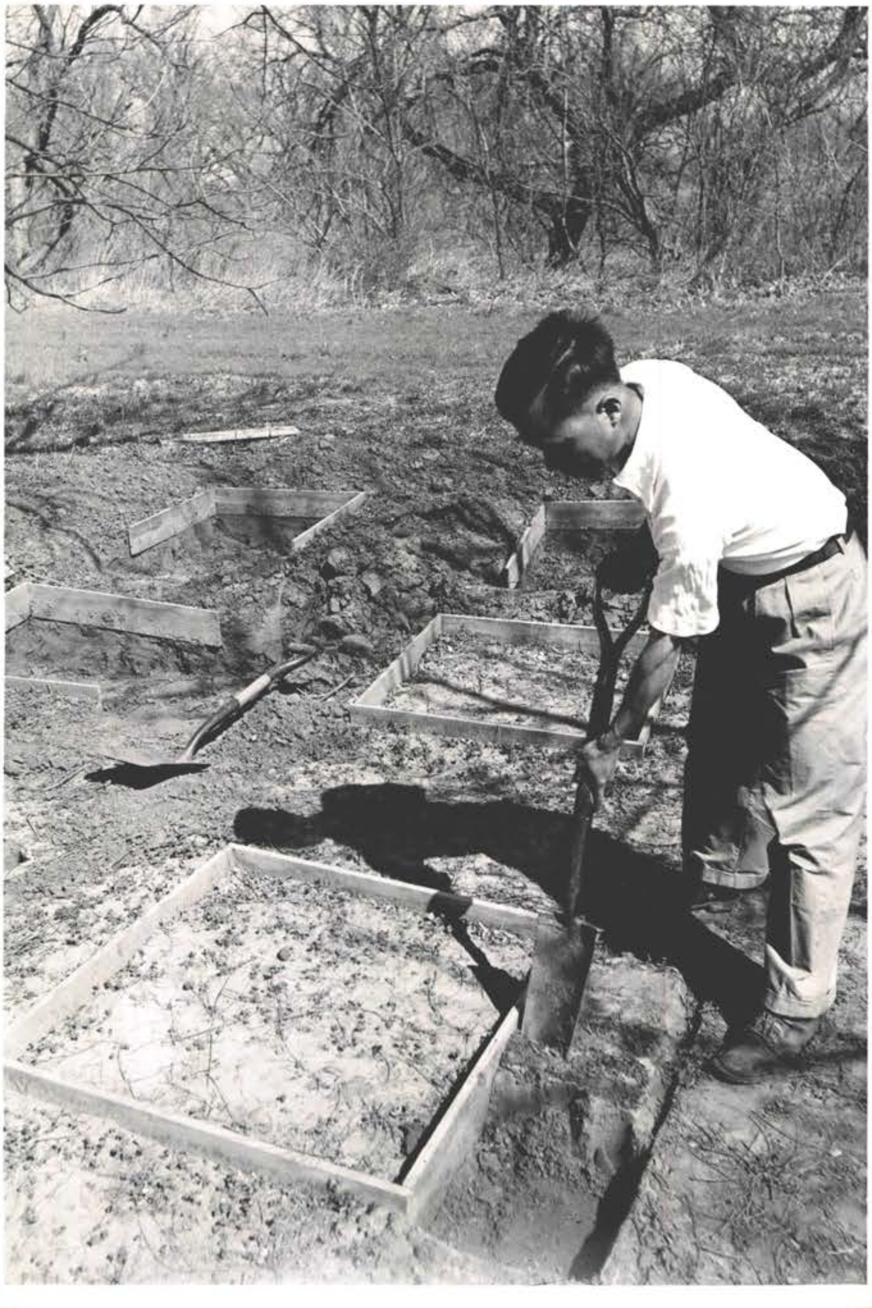

Plate 10. Remove Soil from One Side of a Pen

In Preparation for Digging and Screening the Soil

To Count Larvae

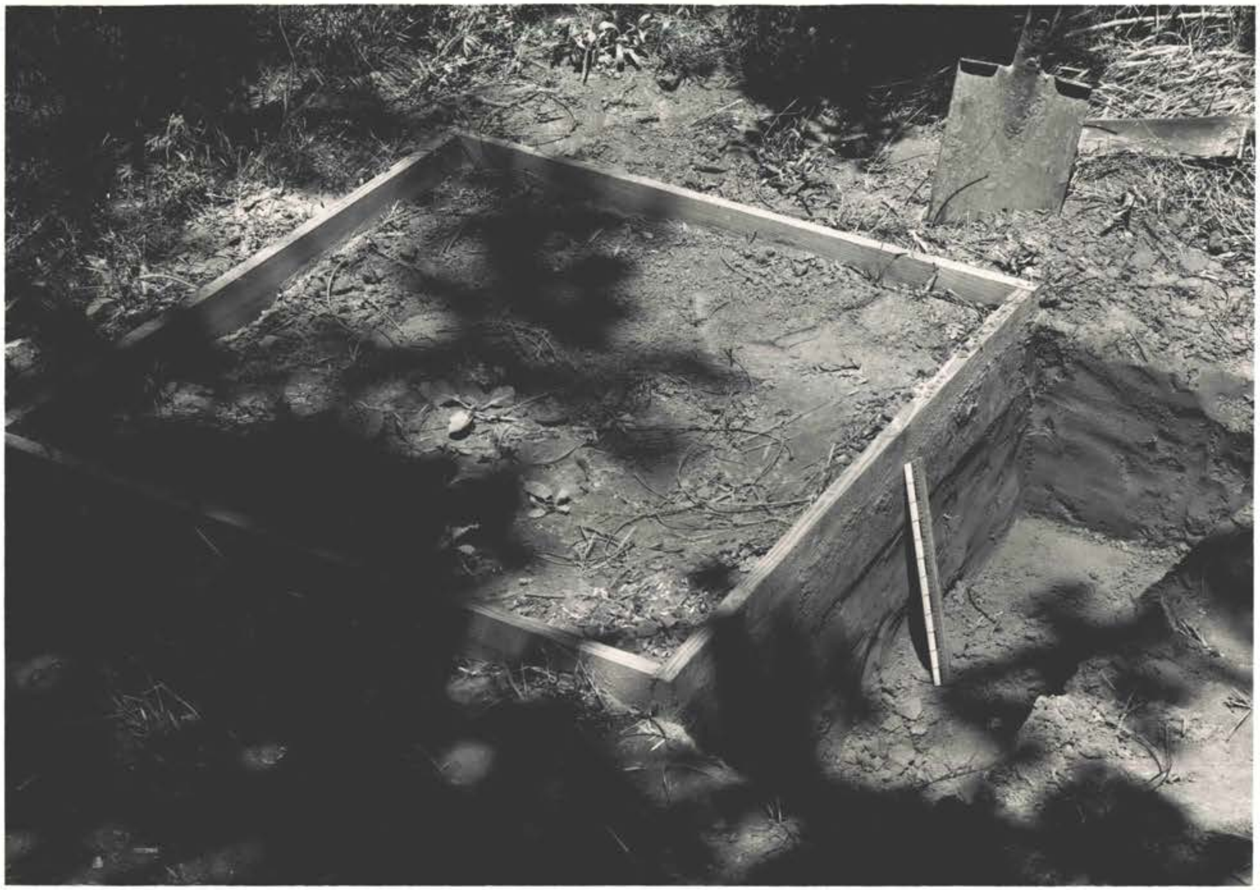

Plate 11. Pen No. 1 with a Hole Dug to a Depth of One Foot on the Outside In Preparation for Examining the Soil

Plate 12. Method of Digging - Removing One Board Before Start

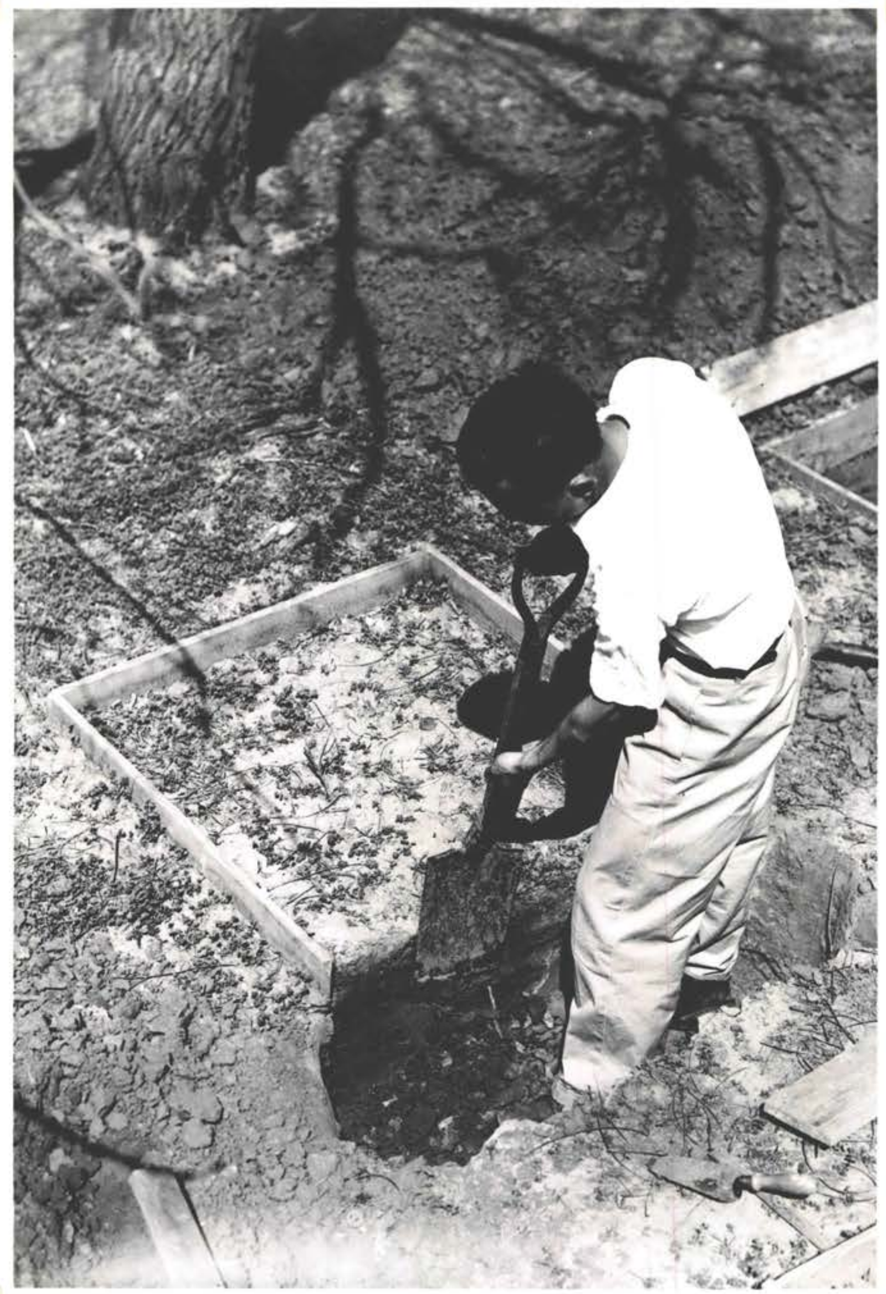

Plate 13. Searching for Larvae in the Pen

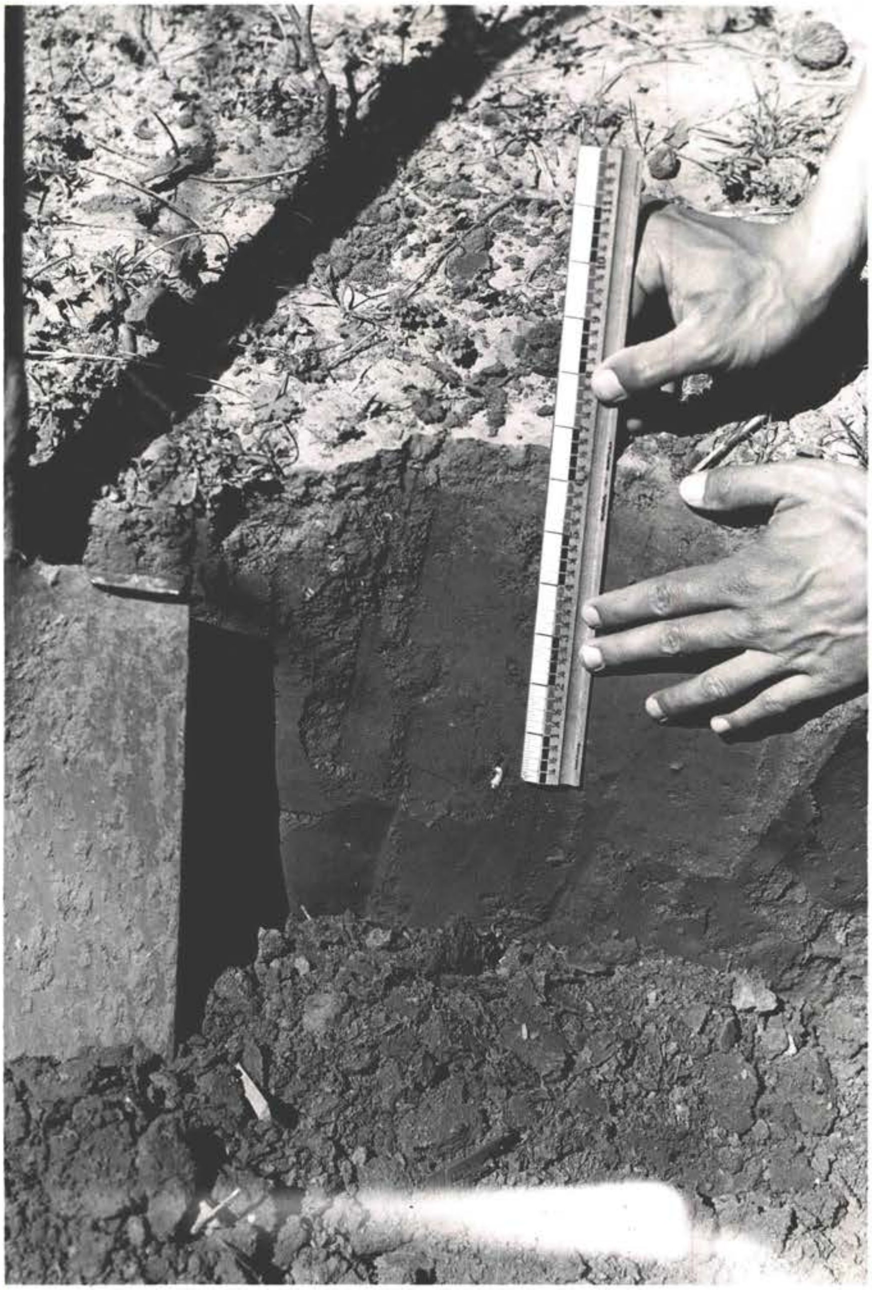

Plate 14. Larva located $6\frac{1}{2}$ inches Below Soil Surface

Plate 15. Pen No. 3 of Spring Application -

A Dead Larva Located at 4½ Inches in Ethylene Dibromide Treatment

Plate 16. A Live Larva Located at a Depth of 4½ Inches in Soil

Plate 17. Pen No. 3 of the Spring Application

With Half of its Area Already Dug.

One Larva is Distinctly Visible

Plate 18. Pen No. 3 - After Completion of Digging Larvae.

Soil to the Depth of One Foot was Entirely Removed

Plate 19. Sifting Soil Through a Screen to Search for Larvae

Plate 20. Dead Larvae Showing Discolored and Blackened Bodies After Treated with Ethylene Dibromide

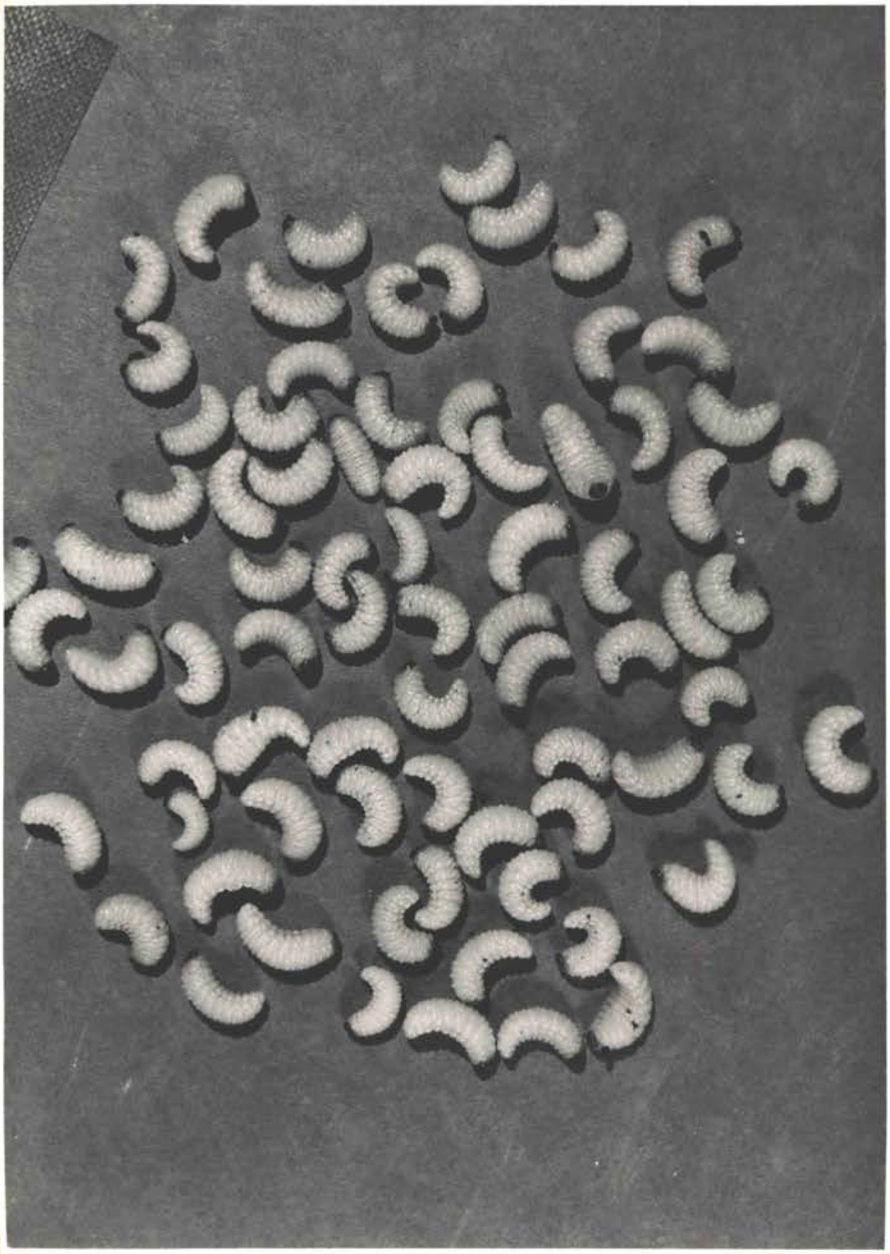

Plate 21. A Group of Larvae Still Alive

Three Months After Treatment With Dichloroethyl Ether

At the Rate of 20 Gallons Per Acre

Plate 22. Treating Soil Around Pecan Tree with Chemicals

For Larva Control

Plate 23. Larva have been removed from infested pecans by woodpeckers.

Nuts collected from tree in January

RESULT

In studying the feeding habits of the pecan weevil, the following facts were obtained.

Observation under a microscope revealed that the beak of the pecan weevil has two tiny teeth which serve as the drilling mechanism for boring holes through the hard shells of the nuts.

A distinctly marked circle around a puncture on the shuck of a pecan could be considered as a characteristic symbol indicating the presence of eggs or larvae inside the nut. The puncture made by a weevil was, in most cases, located near the blossom end of the nut.

In general, two to four larvae were found in an infested nut. As larvae became fully grown they had practically destroyed the kernel, leaving a black, powdered residue in the shell.

Female weevils punctured pecans with their beaks for both the purposes of feeding and depositing eggs, while male weevils punctured for feeding only.

Several larvae inside one pecan might come out successively through the same hole about 1/8 of an inch in diameter bored by the first larva. By contraction and extension movements each larva squeezed its flexible body out of the hole.

Adult insects were not found to be active fliers and they failed to survive the winter months. They began to disappear from the trees about the latter part of October in Stillwater.

The results of larva soil penetration are presented in the tables following:

Depth of Penetration in Inches	Sandy Loam			Clay Loam		
	2 Hours	5 Hours	10 Hours	2 Hours	5 Hours	10 Hours
.5	4	6	5	5	6	6
1	2	10	10	17	7	12
1.5	12	9	7	10	9	10
2	14	9	11	12	11	7
2.5	6	8	3	4	11	6
3	9	5	5	2	5	4
3.5	3	3	5		1	2
4			3			2
4.5			1			1
Total Number of Larva	50	50	50	50	50	50

Table 1. The Depth of Larva Penetration in the Soil

Within 2, 5 and 10 hours respectively

Depth of Penetration in Inches	Sandy Loam				Clay Loam			
	24 Hours	48 Hours	1 Week	2 Weeks	24 Hours	48 Hours	1 Week	2 Weeks
.5	2				3			
1	9	4			14	6	1	
1.5	16	7		3	21	13	7	2
2	24	16	2	2	20	13	8	4
2.5	14	22	7	9	16	24	6	7
3	18	17	9	10	4	17	12	6
3.5	6	15	10	13	5	18	13	6
4	4	7	11	4	7	6	16	16
4.5	3	6	8	21	3	3	5	12
5	3	4	18	15	6		13	17
5.5		2	10	7	1		7	10
6	1		9	8			7	14
6.5			6	4			5	2
7			6	1				4
7.5				3				
8			4					
Total	100	100	100	100	100	100	100	100

Table 2. The Depth of Larva Penetration in Soil Within 1, 2, 7 and 14 Days

Treat-ment Plot	2"		3"		3.5"		4"		4.5"		5"		5.5"		6"		6.5"		7"		7.5"		8"		8.5"		9"		10"		11"		Total	
	A	D	A	D	A	D	A	D	A	D	A	D	A	D	A	D	A	D	A	D	A	D	A	D	A	D	A	D	A	D	A	D	A	D
Pen 1			9		13	1	21		8	1	11		2		4		2																70	2
Pen 2			4	1	5	3	8	8	5	6	4	6			3	1	1	1	1	1								1					31	28
Pen 3			4	2	2	1	3	3	4	1	2	4	2	1			2	1	3					1	2				1		1		26	14
Pen 4	1		7	1	5	4	7	4	4	3	9	1		1			1		1		1												36	14
Pen 5			10		17	1	14	1	18		15		7		1		1				1												84	2
Pen 6			3		7		19		10		11		7		2		2		2				2										65	
Pen 7			7		14		17		13	1	14		8		6		2		4				1										86	1
Pen 8			5	5	12		12		12	2	14	1	8	4	3	1	2		1		1	1		3				1					70	13
Pen 9					2		7	1	13	3	25	4	20	2	9	1	4		3		2												85	11
Pen 10			2		6		14		14		20		9		5	1			2				1										73	1
Pen 11			15	2	11		15		13		14		13		9		2																92	2
Pen 12			3		5		15	1	23		24		8		5				2				1		1								87	1
Total	1		80		109		170		154		179		92		51		21		20		6		9		3		2		1		1		899	

Table 3. Locations of Larva found in the pens of fall treatments.

Larvae in the soil for 20 weeks

*The letters A and D indicate Alive and Dead, respectively

Treat-ment Plot	Soil Depth 2" A	D	3" A	D	3.5" A	D	4" A	D	4.5" A	D	5" A	D	5.5" A	D	6" A	D	6.5" A	D	7" A	D	7.5" A	D	8" A	D	8.5" A	D	9" A	D	10" A	D	11" A	D	Total A	D
Pen 1			1				2		7		22	4	13	2	11	2	12	1	4		2												74	9
Pen 2				1				1		1		2		1																			0	6
Pen 3	1	1			4		14		10		6		6		2																		43	1
Pen 4								7		17		38	1	18		12		4				1											1	97
Pen 5													2		3		1	1	1		2			1	1								10	2
Pen 6									1						1				2				1										5	0
Pen 7			2				11		10	1	16		12	2	11	1	8		11		3												84	4
Pen 8							2		4		10	2	8	2	7		6		10		2	2	5		3		2		1		1		61	6
Pen 9			4		3		4		6		27		8		8		7	2	8	1	4		2										81	3
Pen 10							1						1		2	1			1	1	1				1		1						8	2
Pen 11							6				9		12		11		7		9		8		4										66	0
Pen 12							3		3		11		23		22		9		10		6		6		1		7						101	0
Total	2		8		7		51		60		147		111		94		58		58		31		19		6		10		1		1		664	

Table 4. Locations of larva in the pens of spring treatments.

Larvae allowed 28 weeks in the soil.

*The letters A and D indicate Alive and Dead, respectively

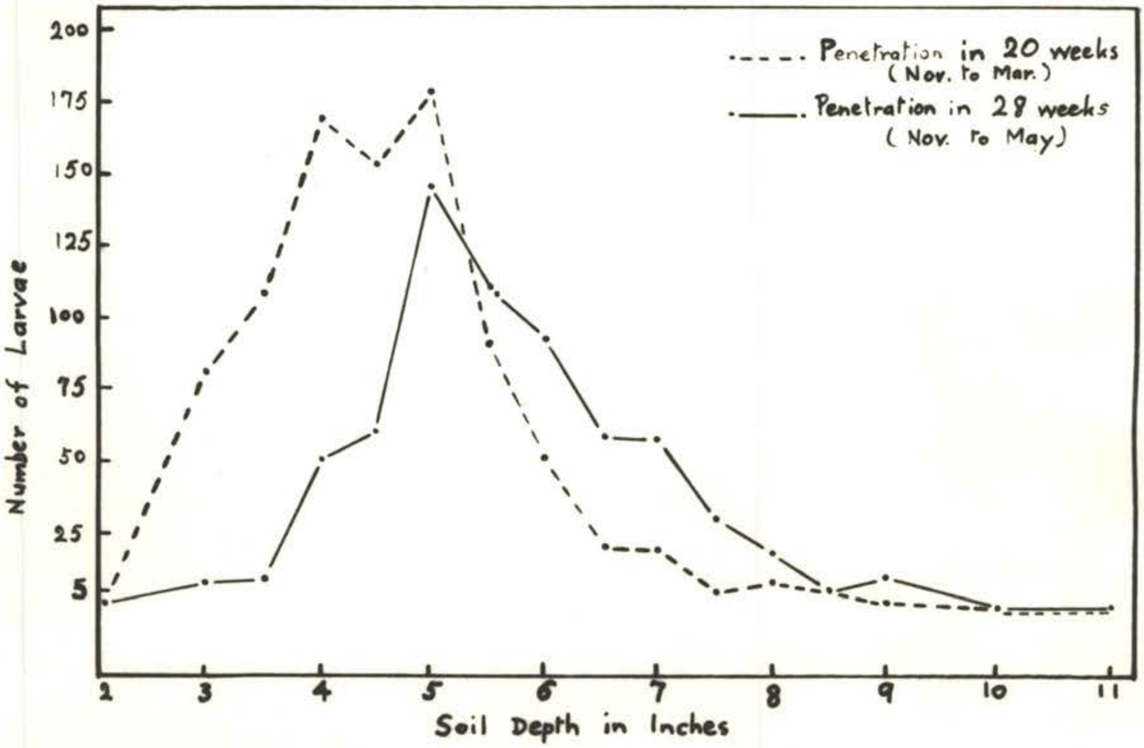

Figure 4. Larvae Penetration in the Pens For the Fall and the Spring Treatments.

The Time Required	Number of Larvae that Burrowed	
	In Sandy Loam Soil	In Clay Loam Soil
3/4 minute	2	0
1 minute	3	0
1 minute, 15 seconds	6	0
1 minute, 30 seconds	4	2
1 minute, 45 seconds	5	4
2 minutes	8	2
2 minutes, 15 seconds	11	3
2 minutes, 30 seconds	7	7
2 minutes, 45 seconds	1	9
3 minutes	3	5
3 minutes, 15 seconds	0	8
3 minutes, 30 seconds	0	6
3 minutes, 45 seconds	0	3
4 minutes	0	2
Total Number of Larvae Tested	50	50

Table 5. Showing the Range of Time in Minutes

Required by Larvae for Burrowing

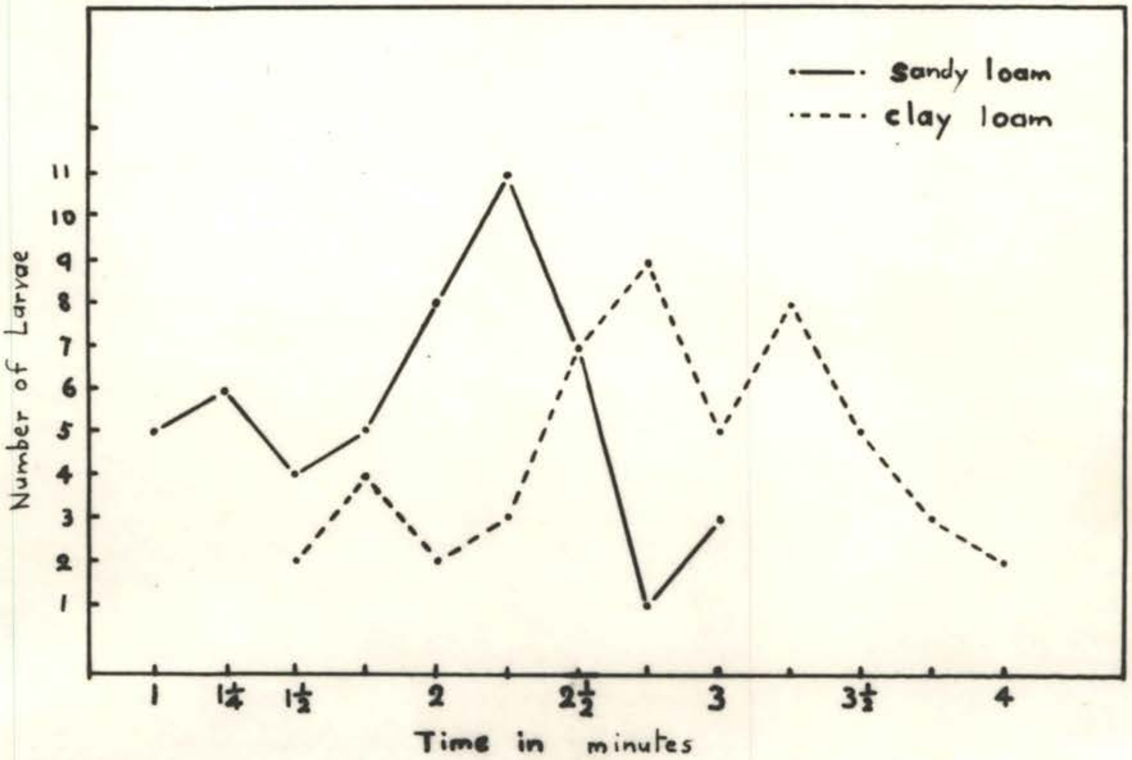

Figure 5. Showing the Time Required by Larvae in Burrowing

Distance of Larva Deviating From the Center Point Measured Horizontally in Inches	Number of Larvae							
	In Sandy Loam Soil				In Clay Loam Soil			
	24 Hours	2 Days	7 Days	14 Days	24 Hours	2 Days	7 Days	14 Days
0 to .49	23	9	15	25	14	24	18	25
.5	8	16	9	9	15	9	8	7
1	2	8	8	12	10	3	4	10
1.5	3	4	4	1	8	6	6	4
2	9	9	10	3	2	8	1	3
2.5	2	3	2		1		3	0
3	3	1	2					1
Total Number of Larvae Tested	50	50	50	50	50	50	50	50

Table 6. Horizontal Movements of Larvae in the Soil

Within 1, 2, 7 and 14 Days Respectively

In 2 to 10 hours most of the larvae penetrated 1 to 2½ inches deep in both sandy loam and clay loam soils. The results showed that when larvae were allowed to penetrate from 2 to 10 hours, they were mostly located 1 to 2 inches deep in the soil. Larvae reached the same range of penetration from 1/2 an inch to 4½ inches in both sandy and clay loam soils.

In 24 hours most larvae penetrated 1 to 3 inches deep in sandy loam soil and 1 to 2½ inches in clay loam soil. Whereas in 48 hours most larvae penetrated 2 to 3½ inches in sandy loam and 1½ to 3½ inches in clay loam soil.

This indicated larvae penetrated about 1/2 an inch deeper during the second day than during the first. While the range of penetration extended from 1/2 an inch to 6 inches deep in the soil, most larvae were located between 1 and 3½ inches.

In 7 days most larvae penetrated 3 to 6 inches deep in sandy loam, and 2 to 5 inches in clay loam soils; while in 14 days most of them penetrated 2½ to 6 inches deep in both types of soil.

These data show that larvae established themselves at a normal depth in the soil during the first week of penetration. There was no significant progress downward during the second week of penetration. Although the range of penetration extended from 1 to 9 inches deep, the majority of the larvae were located between 3 and 6 inches in the soil. They seemed to penetrate slightly deeper in the sandy loam than in the clay loam soil.

When larvae were allowed to stay for a long period of 20 weeks in the orchard soil, 92 per cent of them (835 out of a total of 899) were found in the layer of soil between 3½ to 6 inches deep. The maximum number of larvae was located in the 5 inch layer, while the range of penetration extended from 2 to 11 inches deep.

When larvae were allowed to remain over a period of 29 weeks from November, 1947 to May, 1948, 87 per cent of them (579 larvae out of the total number of 664) were located between 4½ and 7 inches deep in the soil, with the maximum number of larvae also in the 6 inch layer. There was no great difference in the range of maximum penetration between the periods of 20 and 29 weeks.

The data showed that after 6 months most of the larvae were located from 4 to 6 inches deep in an orchard soil.

In determining how long a larva would expose itself upon the surface of the soil, it was found that most larvae could burrow and completely disappear within 1½ minutes to 2½ minutes in sandy loam, and from 2¼ minutes to 3½ minutes in clay loam soils. The results showed that it took a slightly longer time for the larvae to burrow in clay loam than in sandy loam. In general, the average time a larva required to burrow into an ordinary orchard soil was between 2 and 3 minutes.

In testing the horizontal movements of larvae in the soil it was found that larvae would move sidewise from less than 1/2 inch to as far as 3 inches within 24 hours to 3 weeks. Results showed that a majority of larvae were located not more than ½ an inch when measured horizontally from the central point of deviation. This indicated that during burrowing, larvae seemed to have a tendency of penetrating more or less vertically downward into the soil.

Results of the fall treatments (Table 7) showed that Ethylene dibromide and Propylene dichloride were effective in the control of pecan weevil larvae. Ethylene dibromide applied at the rate of 20 gallons per acre killed 75 per cent of the larvae and gave the best control of the materials used in these experiments. Propylene dichloride applied at the rate of 151 gallons per acre (prepared in the form of 10 per cent emulsion) killed 70.5 per cent of the

Fumigants	Pen No.	Rate of Application	Actual Amount and Concentration Used	No. of cc per Injection	Number of Larvae Found After Treated: Alive	Dead	Disintegrated	Per cent Alive
Propylene dichloride	1	2 fl.oz./sq.yd.	$1\frac{1}{4}$ pints/sq.yd. of 10% emulsion	19.7cc (Total 30 injections)	70	2	33	66.6
	2	4 fl.oz./sq.yd.	$2\frac{1}{2}$ pints/sq.yd. of 10% emulsion	39.5cc	31	28	46	29.5
Ethylene dibromide	3	20 gals./acre	16 cc/sq.yd. of 20%	1.2cc (Total 14 injections)	26	14	65	24.7
	4	40 gals./acre	32 cc/sq.yd. of 20%	2.4cc	36	14	55	34.2
Benzene Hexachloride	5	20 lbs./acre	2 gm./sq.yd. add water to 2 pints	Spray	84	2	19	80
	6	30 lbs./acre	3 gm./sq.yd. add water to 2 pints	Spray	65	0	40	61.99
	7	20 lbs./acre (dusting)	2 gm./sq.yd. mix with 20 gm. talc	Dusting	86	1	18	82.9
Dichloro-ethyl ether	8	20 gals./acre	16cc/sq.yd. of 100%	1.2cc (Total 14 injections)	70	18	17	66.6
	9	40 gals./acre	32cc/sq.yd. of 100%	2.4cc	85	11	9	80.9
Chlordane	10	6 lbs./acre	.6 gm./sq. yd. of 50% add water to 2 pints	Spray	73	1	31	69.5
	11	20 lbs./acre	2 gm./sq. yd. of 5% mix with 20 gm. talc	Dusting	92	2	11	87.7
Check	12	UNTREATED			87	1	17	82.8

Table 7. Results of Fall Treatments

* 1 fluid ounce = 29.573cc
1 gallon = 8 pints = 3785cc

larvae and was considered as the second best material tested. The treatment with Ethylene dibromide at 40 gallons per acre killed 65.8 per cent of the larvae and was the third best material used.

Treatments with Benzene hexachloride, Chlordane and Dichloroethyl ether proved ineffective in the control of the larvae. Due to conditions of prevailing low soil temperature during the fall fumigating period, volatility of chemicals might have been checked to some extent which would have lessened their effect on the larvae.

In the spring fumigation tests (Table 8) both Propylene dichloride and Ethylene dibromide were very effective in the control of pecan weevil larvae. The treatment with Propylene dichloride applied at the rate of 151 gallons per acre killed all of the larvae in the pen. Most of the dead larvae had already disintegrated, leaving a small number of blackened and discolored dead bodies found at the time of digging.

The next most effective material was Ethylene dibromide used at the rate of 40 gallons per acre. Of 105 larvae in the treated pen, 97 dead larvae were actually discovered in the soil; thus the killing effect of Ethylene dibromide was extremely high. Only one live larva was found in this same pen.

Benzene hexachloride applied at 30 and 20 pounds per acre, and Chlordane applied at 8 pounds per acre in all three treatments, killed 90 to 95 per cent of the larvae.

Dichloroethyl ether at 1 and 1½ fluid ounces per square yard, Propylene dichloride at 75 gallons per acre and Chlordane at 6 pounds per acre were all ineffective.

The results of the two check plots showed that an average of about 20 per cent of the larvae disappeared or died in the untreated pens.

In summing up the results of both the fall and the spring applications, Ethylene dibromide and Propylene dichloride were found effective in larva

Fumigants	Pen No.	Rate of Application	Actual Amount and Concentration Used	No. of cc per Injection	Number of Larvae Found After Treated: Alive	Dead	Disintegrated	Per cent Alive
				(Total 16 Injections)				
Propylene dichloride	1	2 fl.oz./sq.yd.	1¼ pints/sq.yd. of 10% emulsion	37	74	9	22	70.4
	2	4 fl.oz./sq.yd.	2½ pints/sq.yd. of 10% emulsion	74	0	6	99	0
Ethylene dibromide	3	20 gals./acre	16cc/sq.yd. of 20%	1	43	1	61	40.9
	4	40 gals./acre	32cc/sq.yd. of 20%	2	1	97	7	.9
Benzene Hexachloride	5	20 lbs./acre	1.87 gms./sq.yd. of 6% (add water to 592cc)	37	10	2	93	9.5
	6	30 lbs./acre	2.8 gms./sq.yd. of 6%	37	5	0	100	4.5
Dichloro-ethyl Ether	7	1 fl.oz./sq.yd.	1¼ pints/sq.yd. of 5% emulsion	37	84	4	17	80
	8	1½ fl.oz./sq.yd.	1¼ pints/sq.yd. of 7.5% emulsion	37	61	6	38	58.1
Chlordane	9	6 lbs./acre	.56 gm./sq.yd. of 50% (add water to 592cc)	37	81	3	21	77.1
	10	9 lbs./acre	.84 gm./sq.yd. of 50%	37	8	2	95	7.6
Check	11	UNTREATED			66	0	39	62.9
	12	UNTREATED			101	0	4	96.1

Table 8. Results of Spring Treatments

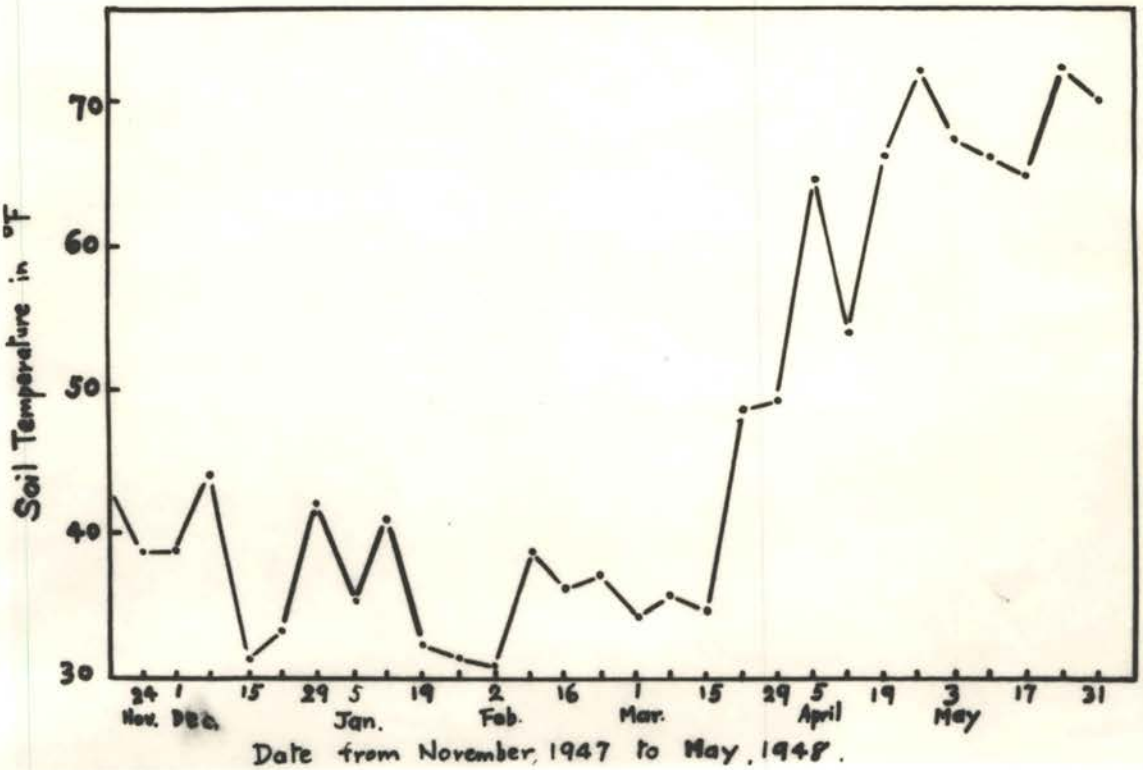

Figure 6. Soil Temperature in the College Pecan Grove From November, 1947 to May, 1948.

control of the pecan weevil. Benzene hexachloride and Chlordane had some toxic effect on the weevil larvae when applied by the injection method during the spring season, but showed no result at all when used as a spray or a dust as surface application during December. Dichloroethy ether was ineffective in both the fall and the spring applications.

Treating the soil around 20 pecan trees with the 5 kinds of chemicals showed no harmful effect on the trees. The growth of these trees was just as normal and unaffected as that of the untreated trees in the same orchard. Consequently, these experiments indicate that pecan trees will tolerate the chemical effect of Propylene dichloride, Ethylene dibromide, Benzene hexachloride, Dichloroethyl ether, as well as Chlordane at the concentrations used in the treatment of soils to control pecan weevil larvae in these experiments.

DISCUSSION

The data in Table 3 and Table 4 indicate most larvae are found at a depth of five inches in the soil. This suggests that a thorough cultivation of the pecan orchard of at least five inches or more in depth may expose the larvae as prey for other insects and birds. Also the mechanical force of plowing may kill some larvae during cultivation. Such birds as woodpeckers preying on the larvae in the nuts are not uncommon (Plate 23). Cultivation to five inches in depth might, however, damage some surface roots.

The same data in Tables 3 and 4 also show that larvae scatter underground from a depth as shallow as 2 inches to one as deep as 11 inches due to the differences in the penetrating ability of individual larvae and the different degrees of compactness of the soil. But only a small number of larvae actually reached beyond 6 inches deep. Therefore, any soil fumigant that will penetrate the soil to such a depth of 6 inches would kill the larvae if the chemical is toxic to them.

From the results indicated in Table 6, it is noted that there is very little horizontal movement underground as larvae burrow vertically downward in the soil. Thus larvae emerging from nuts and dropping to the ground are usually confined to a limited area under the tree. With a concentration of the larvae in the area under trees the possibilities of commercial control by fumigation are thus indicated. Fumigation with a hand-injector is slow, tedious and uneconomical. Mechanical equipment is available which would be practical from an economical standpoint.

Larvae were found an inch deeper in the soil in May than in March. The deeper penetration in the soil of larvae may be due to spring rains in April and May which makes the surface layer of soil too wet for the larvae.

There are three main factors that might affect the efficiency of soil fumigants; namely, (1) the size of soil particles, (2) soil temperature and (3) volatility of the chemicals. As the pens were built in soil of a sandy type, the soil particles were best suited for larva penetration as well as for the thorough dispersion of fumes in the soil. The soil temperature was constantly below 50°F during the first fumigation period from December to March. But the soil temperature was rising and always above 50°F during the second fumigation from April to the end of May. The low soil temperature below 50°F checks the volatility of fumigants and, consequently, the results of the first fumigation were far less promising than that of the second fumigation, though the chemicals were used at the same rates in both cases. In using chemicals for soil fumigation it is desirable that air temperatures be between 50°F and 80°F because air temperature has a direct influence upon soil temperature. The data from Tables 7 and 8 indicate that the best time for larva fumigation in the soil is during the warmer spring months, preferably from April to the end of May. During June the soil temperature rises to around 80°F or above, and chemicals evaporate too fast to be effective in soil fumigation.

As untreated check plots show a considerable number of larvae perishing naturally, it should be noted that the dead larvae found in chemically treated plots were not entirely due to the toxic effect of the materials used. At least a small portion of the casualties counted resulted from natural environmental factors.

A rather pungent odor is left in the soil by both Ethylene dibromide and Propylene dichloride three months after fumigation. The persistency of the odor left in soil by these materials may in part account for their effectiveness in larva control.

Data from the results of soil fumigation indicate the importance of using correct concentrations of the chemicals. When Propylene dichloride was applied at the rate of 2 fluid ounces per square yard of soil, the result was ineffective for there were nearly the same numbers of larvae found alive in the treated plots as in the check plots. But when the rate of application was increased to 4 fluid ounces per square yard, it turned out to be one of the best materials used. The spring application test gave excellent results when Ethylene dibromide was used at the rate of 40 gallons per acre, but was less effective when applied at the rate of 20 gallons per acre. The fall application, however, shows a fairly good control of larvae at both rates of 20 and 40 gallons per acre. But since the spring test was carried out under more favorable conditions with the soil temperature above 60°F, the results should be more reliable. It seems that the dosage recommended by the Dow Chemical Company Laboratory for Ethylene dibromide 20 gallons per acre for the control of nematodes should be doubled for the control of the larvae of pecan weevil.

Benzene hexachloride and Chlordane in the data from Table 7 show no effect in larva control by spray or dust, but in Table 8 they show considerable controlling effect by the injection method. This indicates that surface applications of these materials are completely useless while underground application gives good results in larva control.

All the treatments with Dichloroethyl ether showed no result in larva control. These non-effective results agree with those found by C. B. Nickels in the United States Pecan Field Station at Brownwood, Texas.

One of the vital factors governing an ideal soil fumigant should be its non-phytocidal effect. Since pecan trees showed no harmful effects after treatments with the five kinds of chemicals used in this experiment, it is probably safe to recommend them for practical application in pecan orchards.

CONCLUSION

The pecan weevil causes serious damage to the annual production of pecan nuts in many parts of the State of Oklahoma. Natural enemies and unfavorable climatic environments may account for killing a small percentage of the population of the pecan weevil larvae in soil.

The adult weevils emerge from underground and fly into pecan trees during the late summer. In late summer female weevils deposit eggs in the kernels of nuts. The Stuart and Schley varieties are more susceptible to weevil injury than other varieties. When matured larvae emerge from the nuts on the trees and drop to the ground, they burrow rapidly into the soil, usually in 2 to 5 minutes. Within the first or second week after penetration larvae establish themselves by building cells in the soil.

Most larvae are located 5 to 6 inches deep in the soil, though a fewer number may penetrate as deep as 11 inches. Larvae show no tendency to travel horizontally once they establish themselves in the soil. There is no significant difference between sandy loam and clay loam soils in the depth of penetration of larvae.

According to the results of soil fumigation two chemicals were found effective in the control of pecan weevil larvae. The most effective treatment was the application of Ethylene dibromide at the rate of 40 gallons per acre. The second effective treatment was Propylene dichloride applied at 151 gallons per acre.

Benzene hexachloride and Chlordane applied at 30 and 9 pounds per acre respectively proved to be moderately effective by the injection method. But when they were applied in the form of a spray or dust they were not effective.

Dichloroethyl ether was entirely ineffective in larva control. During cool periods, when soil temperatures were below 50°F, the effects of soil fumigants were lower than when applied at soil temperatures above 50°F. Pecan trees showed no harmful effects when soils around them were treated with Propylene dichloride, Ethylene dibromide, Benzene hexachloride, Dichloroethyl ether and Chlordane.

SUMMARY

1. Weevil-infested nuts can be easily recognized by a characteristic puncture surrounded by a circle on the shuck which sticks tight to the shell of the pecan. Female weevils lay 2 to 4 eggs in the pecan kernel by inserting their ovipositor down the puncture already made by their beaks. It requires about a month's time for the larvae to mature after which they bore a hole through the shell for emergence.
2. The Stuart and Schley varieties are more commonly attacked than other varieties.
3. Larvae can penetrate one or two inches deep in sandy or clay loam soils if they are allowed to burrow two to ten hours. They can reach a depth of $1\frac{1}{2}$ to $3\frac{1}{2}$ inches if allowed to penetrate from 24 to 48 hours. Seven days after penetration, larvae are found at the depth of 4 to 5 inches in the soil. They seem to penetrate slightly deeper in a period of 2 weeks time with the majority of them found 4 to 6 inches deep in the soil. The two types of soil, either sandy or clay loam, result in a very slight difference for depth of larva penetration.
4. Most larvae are found at the depth of 5 inches after remaining in the soil for 20 weeks, and from 6 to 7 inches for 28 weeks although the range of penetration varies from 2 to 11 inches.
5. The average time a larva requires to burrow into the soil of a sandy or clay loam type is 2 to 3 minutes.
6. Larvae show no tendency to move horizontally underground. They seem to penetrate vertically downwards in the soil.
7. Of the 5 kinds of chemicals used for soil fumigation, only Ethylene dibromide and Propylene dichloride gave satisfactory control of pecan weevil larvae.

8. Ethylene dibromide (Dowfume W-40) applied at the rate of 40 gallons per acre killed practically all the larvae in the soil during the spring fumigation. Propylene dichloride applied at the rate of 151 gallons per acre (in an emulsion form) also killed all the larvae in soil. The spring application during April proved to be more effective than the fall application during December. The effectiveness of chemicals is greatly lessened when the soil temperature is below 50°F during the cold months of the year.

9. Benzene hexachloride and Chlordane are not effective when applied to the surface in the form of a spray or a dust. However, they are more effective when injected into the soil. Dichloroethyl ether has no control in the fumigation of larvae.

10. Pecan trees can tolerate the treatments with the 5 kinds of chemicals used for the soil fumigation of pecan weevil in these experiments.

LITERATURE CITED

1. Bissel, T. L. — Experiments on controlling larvae of the pecan weevil by cultural methods. Jour. of Econ. Ent. 24:861-66, 1931.

2. ________ — Structure of the reproductive system of pecan weevil. Ann. of Ent. Soc. of Amer. 30:242-51, 1937.

3. Burnette, F. H. — Pecans. La. State Univ. Bul. 69, 1902.

4. Comstock, J. H. — A manual for the study of insects. Comstock Publishing Co., Ithaca, 1930.

5. Dowfume W-40 for control of soil pest. Dow Chemical Co., Midland, Michigan.

6. Dowkler insecticidal formulations. The Tech. Agr. Bul. Series No. 4. Dow Chemical Co., 1947.

7. Frear, D. E. H. — Chemistry of insecticides and fungicides. p. 137. D. Van Nostrand Co., New York, 1943.

8. Gamtox for wireworms and other soil insects. California Spray-Chemical Corporation, Richmond, California, 1947.

9. Hutt, W. N. — Pecans. North Carolina Dept. of Agr. Bul. 156, 1911.

10. Kearns, C. W., L. Ingle and R. L. Metcalf — A new chlorinated hydrocarbon insecticide. Jour. Ec. Ent. 38(6):661-668, 1945.

11. Kislanko, J. P. — Pecan insects in Mississippi and control. Natl. Pecan Growers' Assoc. pp. 29-51, 1930.

12. Langston, J. M. — Experiments with pecan weevil. Quarterly Bul. of State Planning Board of Mississippi 9:10, 1930.

13. Metcalf, C. L. and W. P. Flint — The destructive and useful insects. Second Ed. pp. 205-210, 1939.

14. Moznette, G. F. — D.D.T. for pecan weevil control in the Southeastern States. U.S.D.A. Agr. Res. Adm. Bur. of Ent. and Pl. Quarantine E-723.

15. ________ — The pecan weevil and latest developments in control. Proc. 41st Ann. Convention S. E. Pecan Growers' Assoc., 1948.

16. Moznett, G. F. and C. B. Nickels — Insects and diseases of the pecan and their control. U.S.D.A. F.B. 1829.

17. Newhall, A. G. Volatile soil fumigants for plant disease control. Soil Sci. 61 No. 1 pp. 67-82, 1946.

18. Phillips, A. M. and J. R. Cole Insects and diseases of the pecan in Florida. University of Florida Bul. 411, 1947.

19. Porter, B. A. Insects affecting Northern nuts. Northern Nut Growers' Assoc. pp. 23-77.

20. Powell, Dwight, S. C. Chandler and V. W. Kelley Pest control in commercial fruit plantings. University of Illinois C-623, 1948.

21. Shuhart, D. V. The pecan in Oklahoma. Oklahoma Agr. Exp. Sta. C-59, 1926.

22. Snapp, O. I. Propylene dichloride for peach tree borer control. Jour. Econ. Ent. 36(5):765-8, 1943.

23. ______ Propylene dichloride for peach tree borer control, second report. Jour. Econ. Ent. 38(4):419-422, 1945.

24. ______ Dichloroethyl ether for control of plum curculio attacking peaches. Jour. Econ. Ent. 32(4):489-490, 1939.

25. ______ Further test of Dichloroethyl ether and of jarring to control plum curculio. Jour. Econ. Ent. 35:514-516, 1942.

26. ______ Further experiment with Dichloroethyl ether for plum curculio control. Jour. Econ Ent. 38(4): 417-418, 1945.

27. Soil fumigation. "Down to Earth". Dow Chemical Co. Vol. 2, No. 4., 1947.

28. Stucky, H. P. and E. J. Kyle Pecan growing. MacMillan Co., New York.

29. Swingle, H. S. Control of the pecan weevil. Jour. Econ. Ent. 28:794-96, 1935.

30. ______ The pecan weevil. Alabama Agr. Exp. Sta. L. 4, 1936.

31. Talbert, T. J. Nut tree culture in Missouri. University of Missouri Bul. 454. pp. 13-15.

TYPIST

RUTH DELANO