PECAN WEEVIL, CURCULIO CARYAE (HORN): COMPARISON OF SAMPLING TECHNIQUES, ESTIMATION OF POPULATIONS, AND DETERMINATION OF THE RELATIONSHIPS BETWEEN CERTAIN PHYSICAL PARAMETERS AND ADULT EMERGENCE

By

DAVID JOHN BOETHEL

Bachelor of Science
Texas A & M University
College Station, Texas
1968

Master of Science
Texas A & M University
College Station, Texas
1970

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of the Oklahoma State University
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Thesis Approved:

Thesis Adviser

Dean of the Graduate College

PREFACE

Emphasis in applied entomology in recent years has centered on the development of pest management programs which utilize several methods of control to keep pests below a level of economic damage. The foundation of all pest management programs is reliable sampling procedures. The studies reported herein deal with evaluation of sampling techniques for the pecan weevil.

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CHAPTER I

INTRODUCTION

The pecan weevil, Curculio caryae (Horn), is considered the most injurious insect attacking pecans in Oklahoma. Losses due to this pest are of the magnitude that control measures are imperative.

At present, insecticides directed at adult pecan weevils are the most widely used method of control; however, concern about variable results has been expressed by both researchers and pecan growers after utilization of various pesticides. Many times the chemicals are deemed faulty when research indicates the shortcomings may be the result of (1) improper timing of insecticide applications, (2) inadequate number of applications, (3) variable onset of emergence of adult pecan weevils, and (4) variable inter- and intra-tree pecan weevil populations. Due to these phenomena, reliable sampling techniques for the pecan weevil are needed.

If pecan growers could predict when the adult stage of the pecan weevil (most vulnerable to chemical control) emerged from the soil, the problem of control due to improper timing of applications might be overcome. Early researchers have postulated that a correlation exists between rainfall and the onset of pecan weevil emergence; however, little quantitative data is available to substantiate this hypothesis.

The objectives of the research reported herein were as follows:

1. To compare several current sampling techniques for detecting onset of adult pecan weevil emergence and evaluate their effectiveness in monitoring seasonal fluctuations in emergence patterns.
2. To evaluate the effectiveness of certain sampling techniques for estimating adult pecan weevil populations.
3. To determine the relationship between certain physical parameters and adult pecan weevil emergence.

CHAPTER II

PECAN WEEVIL: COMPARISON OF SAMPLING TECHNIQUES

Most of the literature pertaining to the pecan weevil has dealt with research on control. One of the earliest control measures involved jarring or shaking limbs of pecan trees to dislodge the weevils onto a canvas sheet from which they subsequently were collected and destroyed (Moznette et al. 1931). The jarring method later evolved into a sampling technique used to determine the need for insecticide applications.

Moznette (1948) reported that for the best control results the 1st insecticide application should be timed by the appearance of pecan weevils on the trees, rather than by set spray dates determined by previous seasons. He recommended applying insecticide when six weevils could be jarred from any tree. Other researchers (Dupree and Beckham 1953; Osburn et al. 1963; Osburn et al. 1966) also recommended this procedure. Hinrichs (1952) and Hinrichs and Thomson (1955) indicated that the 1st application should be made when five or more adult weevils were jarred per tree. Rosburg and King (1958) and Rosburg et al. (1969) recommended control measures when three or more weevils were jarred from each tree.

An alternative to the jarring technique was the development of a simplified cone emergence trap (Raney and Eikenbary 1969) to collect weevils as they emerged from the soil. Raney et al. (1970) utilized the traps along with tents of nylon and cotton cloth to study pecan weevil population density and distribution under "Stuart" pecan trees. When emergence traps were used to time insecticide applications, the damage by pecan weevils was less than 10% at the end of the season (Raney and Eikenbary 1971).

Although they did not use the method to time pesticide applications, Beckham and Dupree (1954) and Hinrichs and Thomson (1955) experimented with tanglefoot spread in bands around the tree trunks to capture pecan weevils as they crawled to the canopy. Nash and Thomas (1972) reported that the use of a substance similar to Tack-Trap® around pecan trees might be an efficient method for sampling adult weevils.

Raney and Eikenbary (1971) suggested that the best way to gauge timing of insecticides for pecan weevils would be to sample by spraying three highly infested trees and checking the number of weevils collected from polyethylene sheets under the trees. Polles and Payne (1973) also advocated the use of a "quick-knockdown" insecticide, Pyrenone®, as a sampling technique for adult weevils.

Although several sampling techniques for adult pecan weevils have been proposed, none have come into widespread use. Until recently, little data existed comparing the different techniques; therefore, studies were conducted in 1972 and 1973 to compare several of the current sampling techniques for detecting the onset of adult emergence and evaluate their effectiveness for monitoring seasonal fluctuations in emergence patterns.

Materials and Methods

1972 Experiment

The 1972 experiment was conducted in an uncultivated pecan orchard near Stillwater, Oklahoma. The only management practice followed since 1950 had been the shredding of weeds beneath the trees. The experimental plot (Fig. 1) was ca. $1\frac{1}{4}$ acre in size, and 10 trees of the "Western" variety were utilized for the sampling studies. In order to reduce variability, the trees were selected for consistency in size and shape with each tree ca. 45 ft. tall and containing ca. 2800 $ft.^2$ in the area encompassed under the drip-line. Each tree was ca. 60 ft. from the neighboring tree.

The following sampling techniques were compared and evaluated on all test trees: (1) placing of cone emergence traps under the trees to catch and hold pecan weevils emerging from the soil, (2) spreading of tanglefoot material around the tree trunks to capture weevils crawling up to the canopy, (3) jarring of lower limbs and collection of dislodged weevils on polyethylene tarp, and (4) spraying of the trees to collect weevils not captured by the previous three methods.

The 1st sampling method used to detect adult weevil emergence consisted of placing 12 simplified cone emergence traps (Raney and Eikenbary 1969) under each of the 10 test trees (Fig. 2). The traps were set out July 21 and checked daily ca. dawn until the experiment was terminated. The pecan weevils found in or on the traps at the time of sampling were removed and recorded as to the tree number and trap location. All weevils collected were sexed according to the technique of Chittenden (1927).

Figure 1. Diagram of the experimental plot showing the location of test trees and "indicator trees" of the "Western" pecan variety. Stillwater, Oklahoma, 1972-1973.

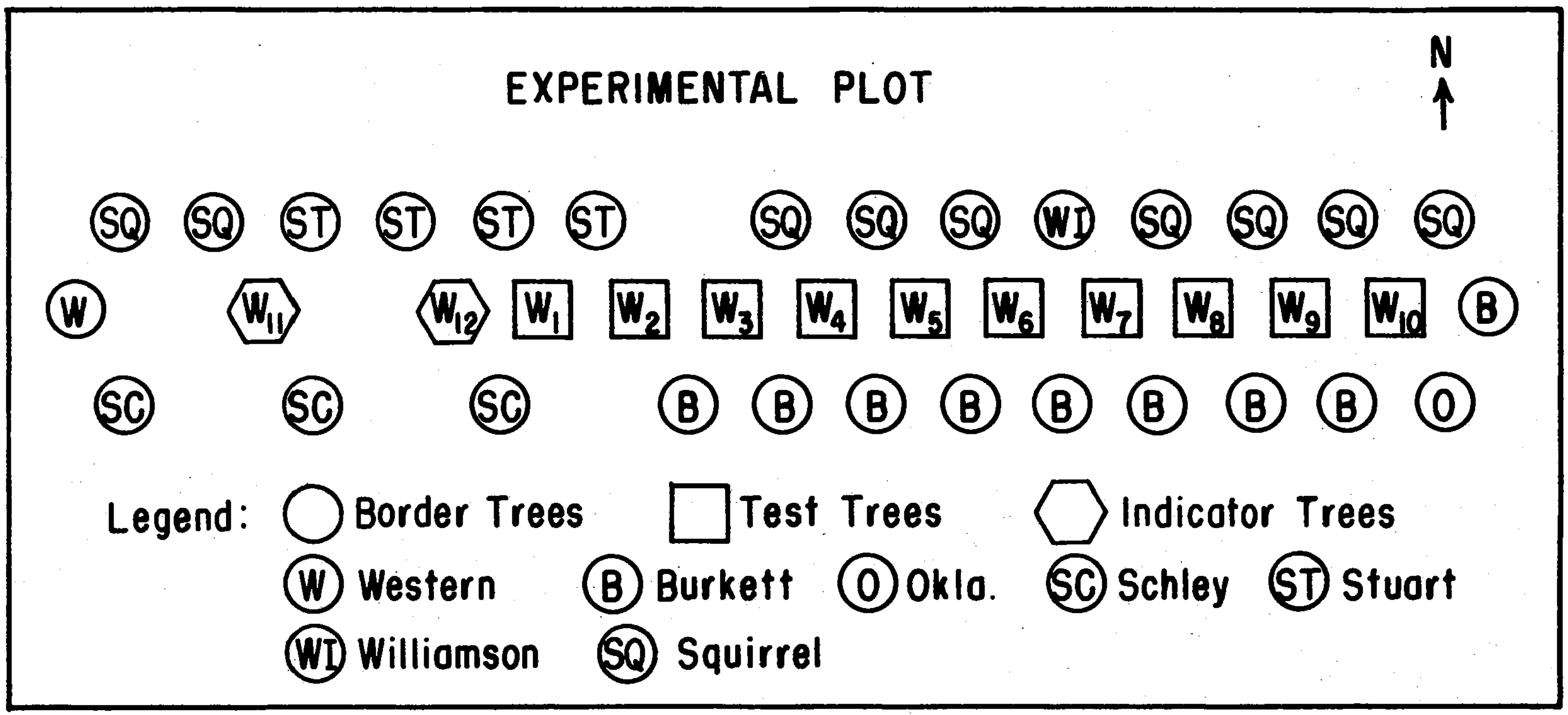
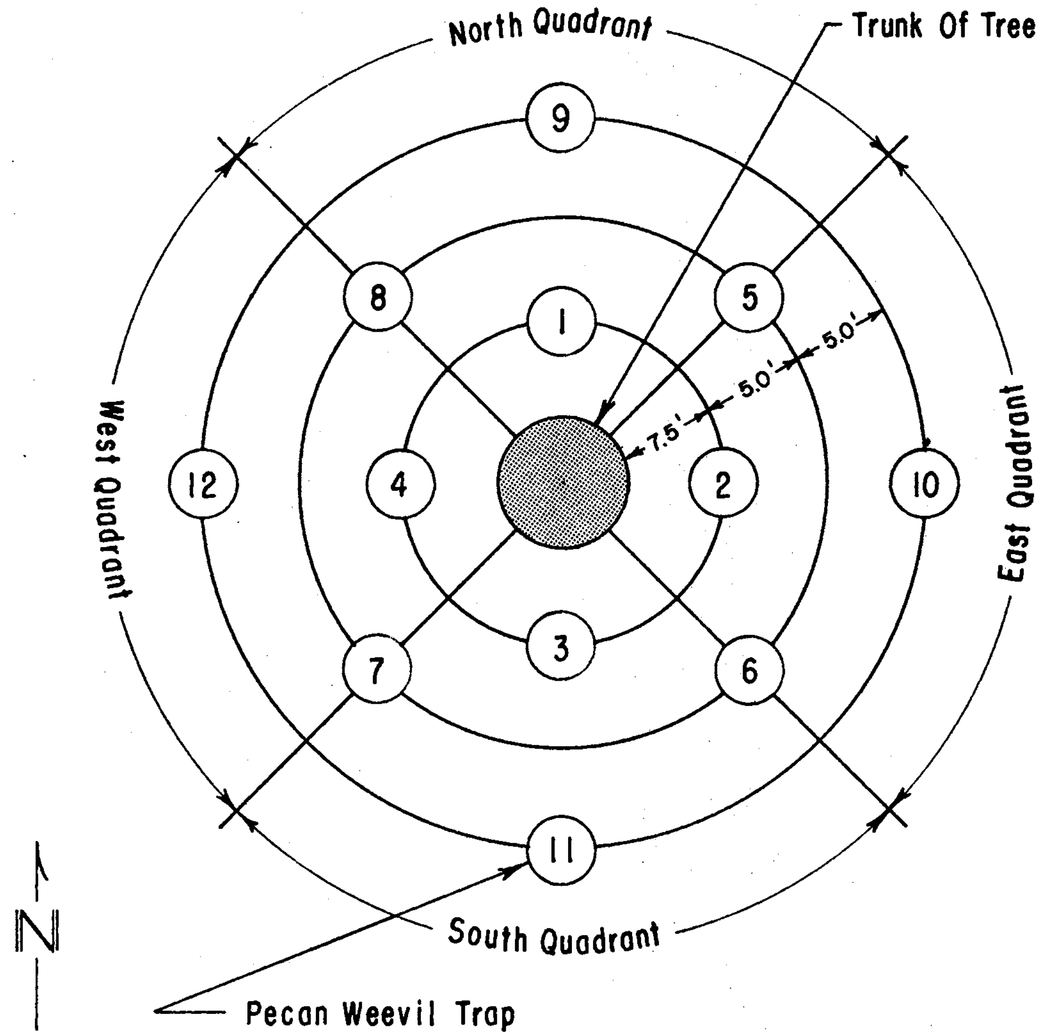

EXPERIMENTAL PLOT
N
SQ SQ ST ST ST ST SQ SQ SQ WI SQ SQ SQ SQ
W W11 W12 W1 W2 W3 W4 W5 W6 W7 W8 W9 W10 B
SC SC SC B B B B B B B B O
Legend: Border Trees
Test Trees
Indicator Trees
W Western
B Burkett
O Okla.
SC Schley
ST Stuart
WI Williamson
SQ Squirrel

Figure 2. The arrangement of emergence traps under pecan trees to collect adult pecan weevils emerging from the soil. Stillwater, Oklahoma, 1972-1973.


North Quadrant
Trunk Of Tree
9
8
5
1
5.0'
5.0'
7.5'
West Quadrant
12
4
2
10
East Quadrant
3
7
6
11
South Quadrant
N
Pecan Weevil Trap

The 2nd sampling technique examined was the use of tanglefoot bands around the trunks of the trees. Two bands of clear polyethylene film (ca. 8 in. wide) were stapled around each tree and covered with tanglefoot. One band was placed 2.5 ft. from the ground level while the other was placed at 5.0 ft. The bands also were set out July 21 and checked daily until the experiment was terminated. The captured weevils were removed, sexed and recorded as to the tree number and band height.

The 3rd sampling technique evaluated was the jarring (shaking) of the lower limbs of the trees to dislodge any weevils that might be present. On alternate days commencing August 1, after the emergence traps and tanglefoot bands had been checked, the traps were moved to the side of the experimental plot. Then black 6 mil polyethylene tarp was spread beneath each tree prior to jarring. One lower limb in each cardinal direction per tree was vigorously shaken by hand. Again, the jarred weevils were collected, sexed and recorded as to tree number and direction.

Spraying of each tree with a low residual insecticide was the 4th sampling technique evaluated. Pyrenone® (5.5 oz. AI/100 gal. water) was delivered by a hurricane mist blower applying ca. 25 gal. of spray per tree. The trees were sprayed August 1 to clear all the weevils from them to begin the experiment. On alternate days (weather permitting, until September 20) after the jarring had been completed, the trees were sprayed to collect those weevils not captured by the other sampling techniques. Twenty to 30 minutes after spraying, the polyethylene tarps were examined for the presence of pecan weevils. Those weevils found were removed from the tarps, sexed and recorded as to tree number. After the tarps had been thoroughly checked, they were folded and moved to the side of the experimental plot and the emergence traps replaced to the original locations.

1973 Experiment

The same experimental plot was utilized to conduct the 1973 sampling studies. The emergence traps and spray techniques were repeated; however, due to the results obtained in 1972, the tanglefoot bands and the jarring techniques were not conducted in 1973.

The two-day sampling regimen was employed in 1973. The emergence traps were observed each day beginning August 1 while the spraying took place on alternate days following the initial spraying on August 9 to clear the trees of weevils.

The 1972 data indicated that some movement of weevils into the test trees from surrounding border trees might have occurred. In order to get some idea about possible movement in 1973, two additional "Western" trees were included in the study. Prior to the onset of weevil emergence, black polyethylene tarp was spread under trees 11 and 12 (Fig. 1), hereafter referred to as "indicator trees," to prevent any weevils from emerging beneath them and moving to the canopies. The tarps extended past the drip-lines of the trees and were secured by placing soil around the edges. On each 1973 sampling date, the "indicator trees" were sprayed to collect those pecan weevils that crawled or flew onto them from surrounding trees.

Methods of Statistical Analyses

Because of numerous zeros encountered in the experiments, the assumptions underlying parametric statistical tests, i.e., normally distributed population with a common variance were avoided, and non-parametric techniques were used for data analyses (Conover 1971). The Friedman two-way analysis of variance by ranks was used to test the hypothesis of no differences among the sampling dates and test trees as measured by the various sampling techniques.

In order to estimate the number of trees required for a specified precision for each sampling technique, a modification of the procedure given by LeRoux (1961) was followed.

Results and Discussion

Sampling Techniques

The days in 1972 when jarring and spraying took place, hereafter referred to as sampling dates, are shown in Table 1. The data shown for the emergence traps and tanglefoot represent those weevils caught on the sampling date and the preceding day. Rainfall and/or high wind occurring at the time of sampling prevented the utilization of the jarring and spray techniques on August 29, 31, and September 7, 9, and 14. As soon as the weather permitted, the test trees were sprayed (September 1, 10, and 16) to clear them, and the two-day sampling regimen resumed.

The sampling dates for 1973 are shown in Table 2. The statistical analyses were performed only on the data collected on two-day intervals for 1972 and 1973.

Table 1. --Comparison of four sampling techniques for adult pecan weevils on 10 "Western" trees. Stillwater, Oklahoma, 1972.

Sampling Dates	No. Weevils/Sampling Technique				Total Weevils
	Traps[a]	Tanglefoot[a]	Jarring	Spray	
Aug. 3	2	0	0	0	2
Aug. 5	2	0	0	0	2
Aug. 7	9	0	0	2	11
Aug. 9	2	0	0	5	7
Aug. 11	3	0	0	9	12
Aug. 13	3	0	0	2	5
Aug. 15	11	1	1	34	47
Aug. 17	2	1	1	30	34
Aug. 19	5	2	0	15	22
Aug. 21	2	0	0	9	11
Aug. 23	13	0	3	53	69
Aug. 25	14	0	0	33	47
Aug. 27	292	11	39	415	757
Sept. 1[b]	401	26	62	817	1305
Sept. 3	46	9	5	367	426
Sept. 5	38	2	6	356	402
Sept. 10[b]	33	2	5	240	280
Sept. 12	12	3	3	222	240
Sept. 16[c]	11	6	2	171	190
Sept. 18	1	1	2	50	54
Sept. 20	1	0	0	19	20

[a] The traps and tanglefoot bands were examined daily. The data appearing represent the pecan weevils collected the preceding day, in addition to the date shown. The results shown for traps represent those collected in or on the traps at the time of sampling.

[b] The data shown are accumulative over five days. The sampling regimen had to be interrupted due to rainfall.

[c] The data shown are accumulative over four days. The sampling regimen had to be interrupted due to rainfall.

Table 2. --Comparison of two sampling techniques for adult pecan weevils on 10 "Western" trees and the number of pecan weevils collected by the spray technique on two indicator "Western" trees. Stillwater, Oklahoma, 1973.

Sampling Dates	No. Weevils/Sampling Technique		Total Weevils	Total Weevils Indicator Trees[b/]
	Traps[a/]	Spray		
Aug. 11	14	72	86	2
Aug. 13	30	92	122	1
Aug. 15	27	71	98	3
Aug. 17	33	116	149	3
Aug. 19	24	183	207	2
Aug. 21	15	172	187	6
Aug. 23	23	65	88	4
Aug. 25	15	103	118	1
Aug. 27	15	184	199	8
Aug. 29	10	146	156	2
Aug. 31	7	81	88	1
Sept. 2	45	402	447	5
Sept. 4	115	336	451	8
Sept. 10[c/]	394	1879	2273	50
Sept. 12	86	1089	1175	179
Sept. 14	29	179	208	22
Sept. 16	17	306	323	99

[a/] The traps were examined daily. The data appearing represent the pecan weevils collected the preceding day, in addition to the date shown. The results shown for traps represent those collected in or on the traps at the time of sampling.

[b/] Total number of pecan weevils collected by the spray technique on the two "indicator trees" on each sampling date.

[c/] The data shown are accumulative over six days. The sampling regimen had to be interrupted due to rainfall.

The results of the rank analyses for 1972 and 1973 are shown in Tables 3 and 4, respectively. The data revealed that significant differences in the number of weevils occurred among sampling dates and among test trees. These differences were detected both years by the trap and spray techniques; however, the tanglefoot and jarring techniques failed to demonstrate these differences. The same pattern existed for sexes with slight exceptions occurring in 1972 for females by the trap technique ($P < 0.10$) and males by the spray technique ($P < 0.05$) when testing for differences among trees.

Jarring. The jarring technique was highly variable; and even at peak emergence (Table 1), the numbers of weevils required to recommend control measures (6 weevils per tree, Osburn et al. 1966) was reached on only three trees. This statement must be qualified because of the two-day sampling regimen that was followed. Had the trees not been sprayed on alternate days, the recommended number of weevils collected by jarring might have been reached earlier in the season. Although the data was collected on the number of weevils jarred per each cardinal direction, statistical analysis was not attempted to detect directional differences, due to the small numbers encountered.

For any sampling technique for pecan weevils to be effective, it must be sensitive to the onset of weevil emergence to enable the investigator, grower, etc. to know when to start monitoring an orchard for weevil emergence. The jarring technique is not reliable for detecting the onset of weevil emergence because the weevils may be in the trees long before the technique is initiated. Due to variable emergence from year to year, a specific starting date cannot be

Table 3. --Calculated and tabulated chi-square values for testing differences among sampling dates and among test trees by each of four sampling techniques for pecan weevils. Stillwater, Oklahoma, 1972.

	Dates		Trees	
Sampling Technique / Sex	Degrees of Freedom	Calculated χ^2	Degrees of Freedom	Calculated χ^2
Tanglefoot				
Males	17	10.32	9	1.82
Females	17	6.42	9	1.22
Weevils[a/]	17	21.78	9	3.41
Jarring				
Males	17	12.45	9	1.95
Females	17	18.25	9	1.67
Weevils	17	21.61	9	2.54
Traps				
Males	17	66.88	9	23.56
Females	17	66.91	9	15.02
Weevils	17	84.52	9	37.51
Spray				
Males	17	112.77	9	19.68
Females	17	121.42	9	29.91
Weevils	17	133.65	9	35.15
All Methods[b/]				
Males	17	113.85	9	35.86
Females	17	124.51	9	39.71
Weevils	17	133.79	9	53.79
Tabulated[c/]				
χ^2 0.10	17	24.77	9	14.68
χ^2 0.05	17	27.59	9	16.92
χ^2 0.01	17	33.41	9	21.67

[a/] "Weevils" represents the analyses when males and females were combined for each technique.

[b/] "All Methods" represents the analyses on the weevils captured by the four sampling techniques, thus, the entire weevil population.

[c/] All calculated χ^2 values that exceed the tabulated χ^2 values are significant at the level indicated.

Table 4. --Calculated and tabulated chi-square values for testing differences among sampling dates and among test trees by each of two sampling techniques for pecan weevils. Stillwater, Oklahoma, 1973.

Sampling Technique / Sex	Dates: Degrees of Freedom	Dates: Calculated χ^2	Trees: Degrees of Freedom	Trees: Calculated χ^2
Traps				
Males	15	51.59	9	36.34
Females	15	57.08	9	31.85
Weevils[a]	15	69.09	9	51.92
Spray				
Males	15	89.22	9	66.36
Females	15	113.65	9	60.86
Weevils	15	112.81	9	79.30
All Methods[b]				
Males	15	85.38	9	71.68
Females	15	118.28	9	65.90
Weevils	15	112.29	9	79.88
Tabulated[c]				
χ^2 0.10	15	22.31	9	14.68
χ^2 0.05	15	25.00	9	16.92
χ^2 0.01	15	30.58	9	21.67

a/ "Weevils" represents the analyses when males and females were combined for each technique.

b/ "All Methods" represents the analyses on the weevils captured by the two sampling techniques, thus, the entire weevil population.

c/ All calculated χ^2 values that exceed the tabulated χ^2 values are significant at the level indicated.

selected; and the method, if initiated early in the season prior to any emergence, probably would become too time consuming to be practical.

When discussing the merits of a sampling method similar to jarring, Morris (1955) stated the technique might be sufficient to find gross relative changes in population. As shown in Table 3, the jarring technique did not detect changes in pecan weevil population for the different sampling dates in 1972. Also, Eikenbary and Raney (1973) found that after vigorous jarring of the entire canopy, many pecan weevils remained in the tree. Thus, it would be difficult to jar a consistent proportion of weevils from a tree and make any control recommendations based on the number of weevils jarred questionable.

Tanglefoot. No differences occurred among sampling dates and among test trees for number of pecan weevils captured in the tanglefoot bands (Table 3). The technique was not sensitive to the onset of weevil emergence because weevils were collected by the trap and spray techniques before any were captured in tanglefoot (Table 1).

In 1972, ca. 1% of the total weevils collected were recovered from the tanglefoot. The trap data were excluded from this calculation because some of those trapped might have flown to the trunks of the trees or crawled up the trunks. Although the number captured in tanglefoot was low, the data compares to that of Raney and Eikenbary (1968), who found while studying the flight habits of the pecan weevil that ca. 7% crawled up the trunks of the trees. Their data might have been an over-estimation, because some of the weevils in their study were released near the base of the tree, thus increasing the probability of the weevils walking rather than flying to the trees. Although Beckham and Dupree (1954) reported that they captured 17% of the weevils in tanglefoot, this undoubtedly was an over-estimation. The jarring technique was used to measure the total population, and some weevils probably remained in the tree after jarring.

Raney and Eikenbary (1968) also found that more males than females crawled to and up the trees. In the 1972 study, ca. twice as many males as females (41 to 23) were captured in tanglefoot (all data in Table 1 included); however, ca. 1/3 of the weevils were recovered from the higher band. Again, twice as many males as females (15 to 7) were captured in the 5 ft. band. A question arises whether those weevils collected in the higher band flew to the tree or possibly walked over the lower band. The author observed some weevils doing the latter and that the stickiness of the tanglefoot diminished as the season progressed, due to weathering. Perhaps some weevils crawled up the trees, but upon encountering the tanglefoot, flew to the canopy.

Due to the extreme variability in the number of weevils captured in tanglefoot during the 1972 experiment, it did not appear that the method would be effective as a sampling technique.

Spray. The spraying of the trees with Pyrenone® yielded the largest number of weevils (Tables 1 and 2) and might give an absolute measurement of the weevils present in a tree. Muir and Gambrill (1960) found that a similar method led to recovery of only 48-78% marked released mirids; however, partial efficiency does not appear to be a problem with Pyrenone® for collecting pecan weevils. Eikenbary (1971; unpublished data) utilized the compound to collect pecan weevils and followed shortly after with another insecticide. He found that Pyrenone® gave reliable results.

Significant differences among sampling dates and test trees occurred for the number of pecan weevils collected after spraying with Pyrenone® thus indicating the technique was sensitive to changes in pecan weevil populations over the 1972 and 1973 emergence periods. The least amount of variability was associated with the spray technique; however, the technique is not a good indicator of the onset of weevil emergence unless the spray is applied at frequent intervals throughout the entire period during which emergence is likely to occur. Pecan weevil emergence is known to have occurred under Oklahoma conditions as early as late July and as late as late September (Hinrichs and Thomson 1955). Since this period is approximately two months long, the spray technique would have to be initiated early thus becoming expensive in time and materials.

As shown in Table 1 and 2, a majority of the pecan weevils emerged August 27 - September 1 and September 4 - September 12 for the years 1972 and 1973, respectively. Criswell (1974; personal communication) observed that female weevils are capable of depositing eggs the 2nd day following emergence and that most do so within five days after leaving the soil. Thus the pecan weevil has the potential to cause heavy damage in a period of a few days. This phenomenon stresses the need for frequent monitoring of the activity of the weevil. To sample with Pyrenone® at intervals of two to five days might be prohibitive.

<u>Traps</u>. When the emergence traps were checked daily ca. dawn, pecan weevils were observed outside the traps resting beneath the lids that held the glass jars above the traps. These weevils in addition to those found inside the traps were collected. The weevils on the

outside rarely moved about during the time the traps were checked (0530-0630 h) and even when some weevils were removed, those adjacent on the outside of the traps failed to take flight. For several days, the author observed weevils on the outside of the traps and found that most did not leave the traps until later in the day ca. 1000 h.

Harp (1970) reported that it was common to find pecan weevils congregated on the outside of emergence traps which contained newly emerged adult weevils. He assumed that an attractant might be responsible for this behavior. Another explanation might be that of Raney and Eikenbary (1968) who noted that before taking flight pecan weevils walked around on the ground trying to locate the highest point from which to take flight. Perhaps, the weevils were exhibiting this behavior but stopped upon reaching the lids at the tops of the traps.

Since weevils can be captured on the outside of emergence traps, the efficiency of this sampling technique improves due to the capturing of those weevils emerging from nearby areas not covered by traps. In order to utilize this phenomenon, however, the emergence traps should be checked at the same time each day probably during the early morning hours. Shepard (1973; personal communication) recently tested a pecan weevil cone emergence trap that is designed to capture weevils crawling up the outside of the traps. His results indicated that the trap was more efficient in monitoring population fluctuations of pecan weevils than the standard cone emergence trap.

The emergence traps are good indicators of the onset of weevil emergence (Tables 1 and 2) and in 1972 and to a lesser extent in 1973 were excellent detectors of peak emergence. As can be seen in Fig. 3 and 4, the trap data followed a pattern fairly consistent with

Figure 3. Relationship between the number of pecan weevils collected in emergence traps and the total pecan weevil population collected by all sampling methods on each sampling date. Stillwater, Oklahoma, 1972.

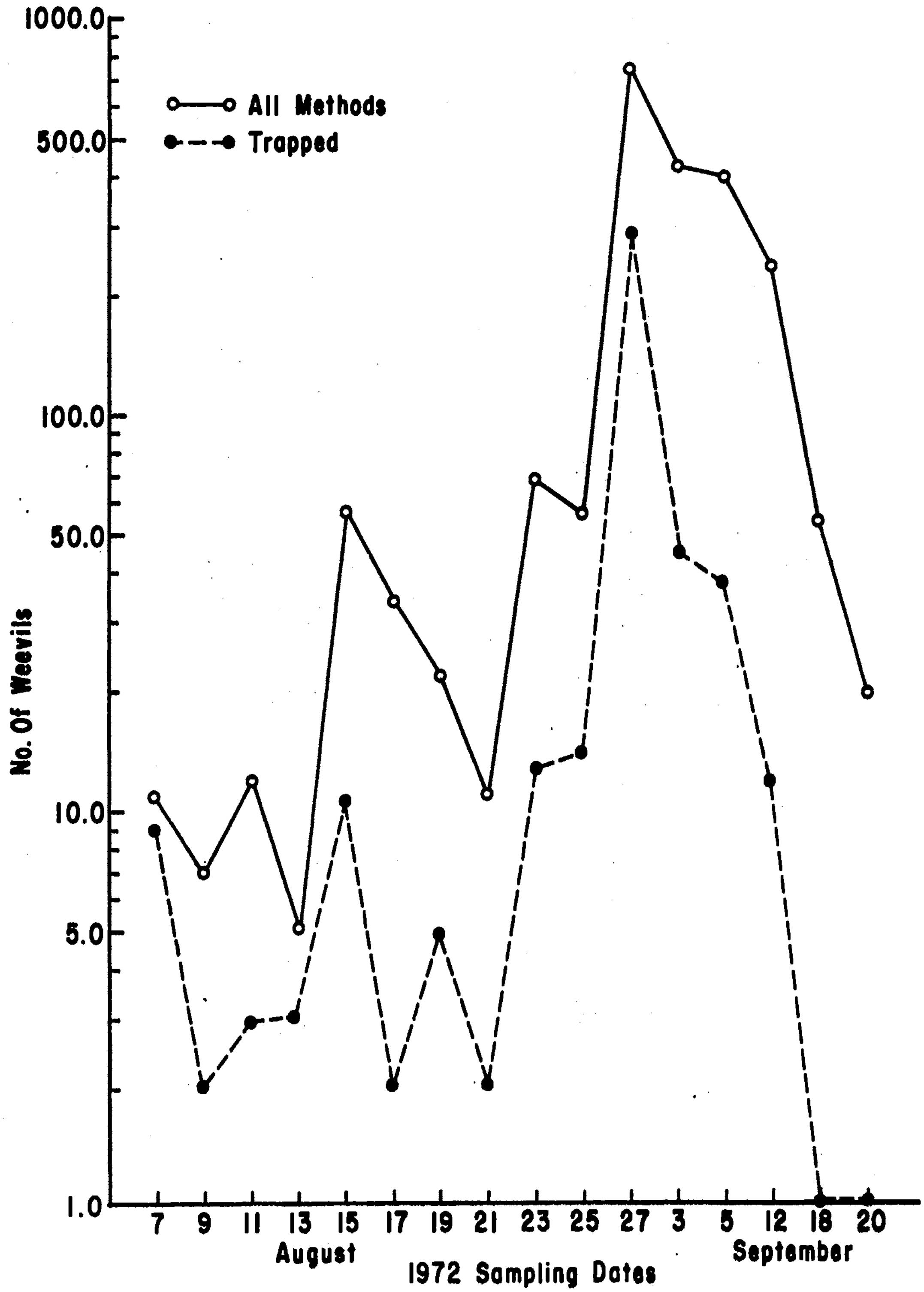
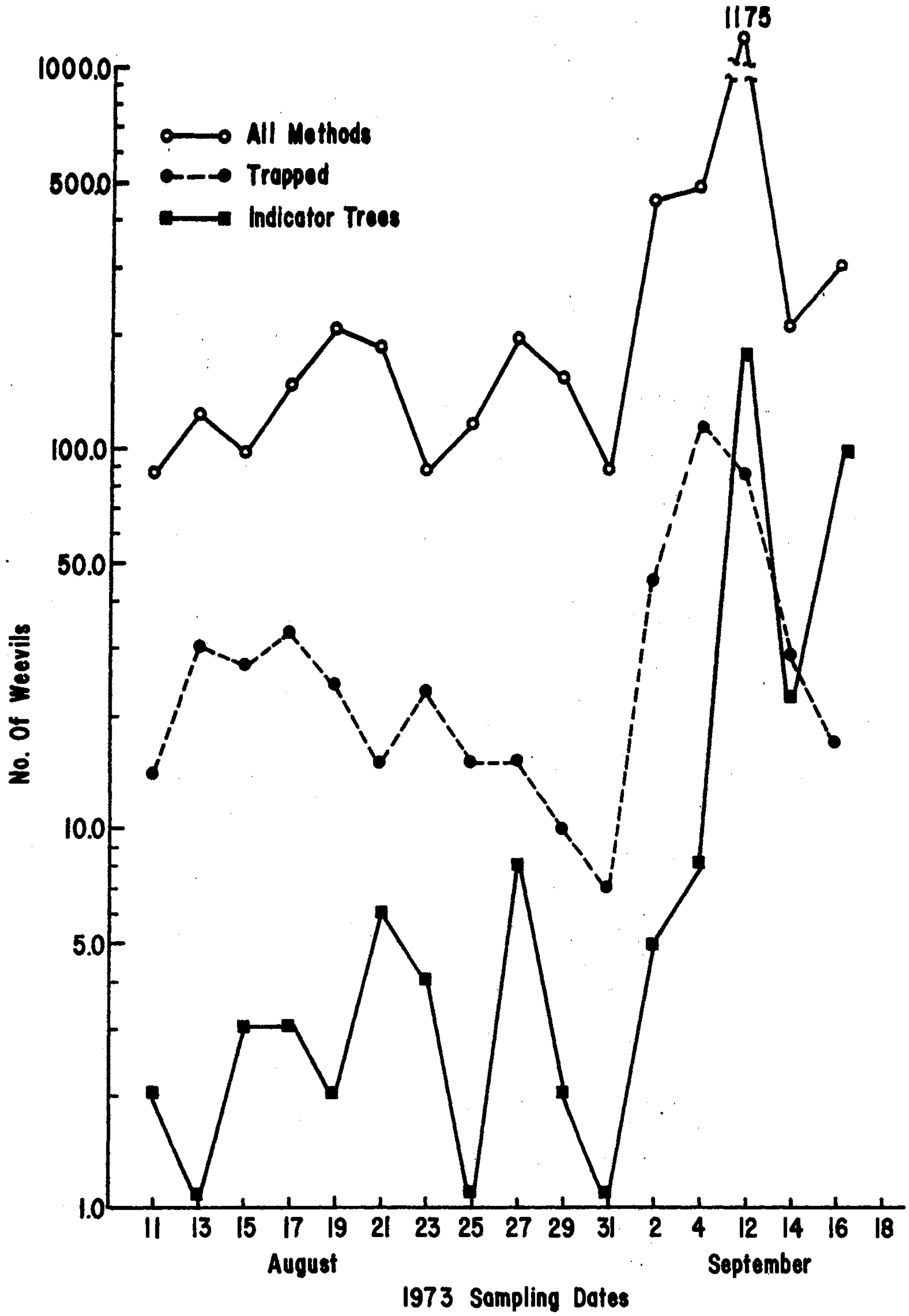

All Methods
Trapped
1000.0
500.0
100.0
50.0
10.0
5.0
1.0
No. Of Weevils
7
9
11
13
15
17
19
21
23
25
27
3
5
12
18
20
August
September
1972 Sampling Dates

Figure 4. Relationship among the number of pecan weevils collected in emergence traps, the number of pecan weevils collected on the "indicator trees," and the total pecan weevil population collected by all sampling methods on each sampling date. Stillwater, Oklahoma, 1973.


1175
1000.0
500.0
100.0
50.0
10.0
5.0
1.0
All Methods
Trapped
Indicator Trees
No. Of Weevils
11 13 15 17 19 21 23 25 27 29 31 2 4 12 14 16 18
August
September
1973 Sampling Dates

that of the total population ("all methods") as measured by combining the number of weevils collected by all the sampling techniques. Thus the traps were effective for detecting population fluctuations during the two years of study.

In 1972, it was observed that on the later sampling dates (September 3, 5, 12, 18, 20) a smaller % of the population was recovered by the trap technique. To explain this phenomenon, it was hypothesized that movement of weevils onto the test trees from surrounding border trees might have occurred. If the emergence pattern was identical throughout the orchard, those weevils collected by the spray technique on the later sampling dates probably emerged on or shortly after August 27 under trees surrounding the test plot. Since the entire orchard other than the test trees was not sprayed, it seems plausible that the weevils dispersed into the test area.

Again in 1973, it was observed that on the later sampling dates (September 12, 14, 16) a smaller % of the weevil population was recovered by the trap technique than earlier in the season. As can be seen in Fig. 4, the number of weevils collected by the spray technique from the "indicator trees" increased on the later sampling dates thus substantiating the hypothesis concerning movement into the test trees. Why the movement occurred late in the pecan weevil season after peak emergence is unknown. Perhaps, overcrowding occurred on the border trees after peak emergence and weevils moved from an area of high concentration into an area of low concentration. Since the test trees were sprayed with Pyrenone® on alternate days, more oviposition sites might have been available on the test trees. These explanations are speculative and their verification or rejection should be decided after further research.

The emergence traps have the advantage of holding weevils thus enabling the observer to know when onset of emergence occurs. If checked frequently at a predetermined time, the weevils captured on the outside of the traps can be utilized in the same manner. The results of the studies reported herein indicated that the technique was effective for detecting seasonal fluctuations in pecan weevil emergence and, other than the spray technique, was the least variable. As mentioned before, weevils can achieve peak population in a short time thus making constant monitoring imperative. Of the sampling techniques studied, the emergence traps probably were the best suited to meet this requirement.

Estimation of the Number of Trees to be Sampled

The total number of pecan weevils collected on each of the test trees for the 1972 and 1973 sampling dates are presented in Table 5. The largest number of weevils were collected from tree # 6 and the smallest number from tree # 8 . These trees were separated by 120 ft. The data confirmed reports of numerous researchers who observed that certain trees in an orchard had large infestations of pecan weevils when nearby trees were virtually uninfested. This phenomenon presents problems in sampling for the pecan weevil because inter-tree variation in populations greatly affects the number of trees to be sampled.

Table 5. --Total number of pecan weevils collected per tree by all sampling techniques. Stillwater, Oklahoma, 1972-1973.

	Tree Number									
Year[a]	1	2	3	4	5	6	7	8	9	10
1972	154	166	248	353	286	320	131	71	179	262
1973	216	227	273	610	430	744	361	283	405	553
Total	370	393	521	963	716	1064	492	354	584	815

[a] Only data that was collected on two-day intervals (sampling dates) for each year were included.

A modification of the procedure of LeRoux (1961) was followed to estimate the number of pecan trees to be sampled for a specified precision for each sampling technique. The following calculation was used:

$$\sqrt{n} = \frac{\sqrt{b(TMS)}}{P(b\bar{X})}$$

where

n = number of trees to be sampled

P = % standard error of the mean

$\bar{X}$ = mean number of weevils for each sex

TMS = total mean square

b = number of sexes = 2.

The estimated number of trees to be sampled for a 10% and 20% error of the mean by each sampling technique for the 1972 and 1973 sampling dates are shown in Tables 6 and 7, respectively. On many of the 1972 sampling dates, few pecan weevils were collected by the jarring and tanglefoot techniques; therefore, the data from these methods were combined with the trap data and are referred to as "mechanical" in the tables. "All" refers to the data of all the methods combined, thus the entire weevil population.

Morris (1955) reported that the required sample size was influenced by the mean level of the spruce budworm population. At moderate to high populations, the required sample size was fairly constant but at low populations it increased rapidly. In both 1972 and 1973, this was the situation with the pecan weevil. On the earlier

Table 6. --Estimation of number of trees to be sampled for a 10% and 20% error of the mean by three sampling techniques for pecan weevils. Stillwater, Oklahoma, 1972.

Sampling Date and Sampling Technique	C. V.	Number of Trees 10%	20%
August 7			
Mechanical[a/]	107.9	116	29
Traps	107.9	116	29
Spray	217.6	474	118
All[b/]	97.6	95	24
August 9			
Mechanical	217.6	474	118
Traps	217.6	474	118
Spray	125.7	157	39
All	98.9	98	24
August 11			
Mechanical	230.7	532	133
Traps	230.7	532	133
Spray	107.9	116	29
All	104.0	108	27
August 13			
Mechanical	172.7	298	75
Traps	172.7	298	75
Spray	217.6	474	118
All	155.6	242	61
August 15			
Mechanical	113.1	128	32
Traps	97.6	95	24
Spray	81.1	66	16
All	77.0	59	15
August 17			
Mechanical	145.1	211	53
Traps	217.6	474	118
Spray	62.1	39	10
All	60.5	37	9
August 19			
Mechanical	118.6	141	35
Traps	155.6	242	61
Spray	100.9	102	25
All	83.2	69	17

Table 6. (Continued).

Sampling Date and Sampling Technique	C. V.	Number of Trees 10%	20%
August 21			
Mechanical	217.6	474	118
Traps	217.6	474	118
Spray	129.7	168	42
All	106.1	112	28
August 23			
Mechanical	65.5	43	11
Traps	88.4	78	20
Spray	75.6	57	14
All	64.3	41	10
August 25			
Mechanical	123.1	154	38
Traps	123.1	154	38
Spray	64.1	41	10
All	48.5	24	6
August 27			
Mechanical	44.1	19	5
Traps	45.4	21	5
Spray	54.1	29	7
All	47.5	23	6
September 3			
Mechanical	45.0	20	5
Traps	53.8	29	7
Spray	28.7	8	2
All	27.6	8	2
September 5			
Mechanical	47.9	23	6
Traps	63.8	41	10
Spray	35.5	13	3
All	34.6	12	3
September 12			
Mechanical	67.0	45	11
Traps	70.5	50	12
Spray	37.3	14	3
All	35.1	12	3

Table 6. (Continued).

Sampling Date and Sampling Technique	C. V.	Number of Trees 10%	20%
September 18			
Mechanical	145.1	211	53
Traps	316.2	1000	250
Spray	47.2	23	6
All	46.6	22	5
September 20			
Mechanical	316.2	1000	250
Traps	316.2	1000	250
Spray	66.0	44	11
All	64.9	42	11

a/ "Mechanical" represents the analyses when the results for jarring, tanglefoot, and traps were combined.

b/ "All" represents the analyses when the results of all the techniques were combined.

Table 7. --Estimation of number of trees to be sampled for a 10% and 20% error of the mean by two sampling techniques for pecan weevils. Stillwater, Oklahoma, 1973.

Sampling Date and Sampling Technique	C.V.	Number of Trees 10%	20%
August 11			
Traps	98.8	98	24
Spray	62.2	39	10
All[a]	62.4	39	10
August 13			
Traps	70.9	50	13
Spray	55.6	31	8
All	54.3	30	7
August 15			
Traps	66.4	44	11
Spray	70.0	49	12
All	57.7	33	8
August 17			
Traps	80.2	64	16
Spray	54.0	29	7
All	51.8	27	7
August 19			
Traps	73.1	53	13
Spray	43.5	19	5
All	38.7	15	4
August 21			
Traps	80.2	64	16
Spray	37.0	14	3
All	35.6	13	3
August 23			
Traps	94.1	89	22
Spray	74.9	56	14
All	68.6	47	12
August 25			
Traps	97.6	95	24
Spray	59.9	36	9
All	54.8	30	8

Table 7. (Continued).

Sampling Date and Sampling Technique	C. V.	Number of Trees 10%	20%
August 27			
Traps	121.9	149	37
Spray	48.9	24	6
All	48.4	24	6
August 29			
Traps	107.6	116	30
Spray	39.3	16	4
All	38.9	15	4
August 31			
Traps	98.8	98	24
Spray	56.4	32	8
All	57.4	33	8
September 2			
Traps	67.7	46	12
Spray	59.4	35	9
All	58.7	35	9
September 4			
Traps	68.9	48	12
Spray	52.3	27	7
All	52.9	28	7
September 12			
Traps	59.0	35	9
Spray	23.0	5	1
All	24.3	6	2
September 14			
Traps	62.2	39	10
Spray	39.5	16	4
All	36.9	14	3
September 16			
Traps	77.6	60	15
Spray	36.7	14	3
All	35.0	12	3

a/ "All" represents the analyses when the results of all the techniques were combined.

sampling dates when the population level was low, more trees were required for a specified precision; however, near peak emergence each season, the number declined.

When studying pests of apples, LeRoux (1961) stated that the 10% standard error could be used for intensive studies and that the 20% standard error could be used for less intensive studies. Due to the lack of knowledge concerning the damage caused by various population levels of pecan weevils, it is difficult to determine the degree of precision required for sampling this pest.

The variation associated with the pecan weevil population and consequently each sampling technique was less in 1973 than 1972, thus resulting in more trees being estimated for 1972. As the data in Tables 6 and 7 demonstrate, on most sampling dates the estimated number of trees to be sampled for a 10% standard error were too large to be practical. The estimates for a 20% standard error were considerably lower on most sampling dates in 1973 and dates around peak emergence in 1972. Those estimates probably represent realistic numbers of trees which could be sampled by the techniques.

In general, fewer trees were needed for a desired precision for the spray technique when compared with the trap technique. The number of trees sampled becomes a limiting factor for each of the two techniques; however, because of cost in time and materials, the limit would be reached sooner with the spray technique. For example, it would be easier and more economical to sample 10 trees by the trap technique than to sample 10 or even fewer trees by the spray technique. Since frequent monitoring also is desirable, the sample size for the spray technique would be further limited.

Summary

In 1972, four sampling techniques for adult pecan weevils were compared. The results obtained with the jarring and tanglefoot techniques were highly variable, and the techniques were not sensitive to the onset of adult emergence or to seasonal fluctuations in the emergence patterns. Since less variation was associated with the trap and spray techniques and they did detect significant differences in pecan weevil numbers among sampling dates and among test trees, those two techniques were evaluated the following year. Similar results were achieved in 1973.

The number of trees required to be sampled for a specified precision were estimated for each of the sampling techniques. It was found that the sample size was influenced by the pecan weevil population level. At low populations, higher numbers of trees were required for a specified precision. Estimates of the number of trees required for a 20% standard error of the mean by the spray and trap techniques were relatively small for most sampling dates in 1973 and dates near peak emergence in 1972.

Until information is available concerning crop injury levels associated with various levels of pecan weevil populations, it is difficult to recommend any technique. These studies compared some of the current techniques used to sample adult pecan weevils. The results indicated that further studies probably should concentrate on the trap and spray techniques or some combination of the two.

Stern (1973) stated, "Of course there are pests for which years of trial-and-error studies are required to develop proper sampling

techniques." From the results of the studies reported herein, this statement appears to be true for the pecan weevil.

CHAPTER III

PECAN WEEVIL: ESTIMATION OF POPULATIONS

Presently, insecticides are the most widely used method of control for pecan weevils. As with most insect pests, sparse information is available as to the pecan weevil population density that causes economic damage. Pesticide applications usually are made when the mere presence of pecan weevils are observed in an orchard. The hazards of such an approach, e.g. unnecessary applications, resistance, ecological upsets, adverse environmental impact, etc. generally are recognized by most researchers, and the need for economic thresholds for the pecan weevil is evident. Of equal importance is the need for a device to determine when the economic thresholds have been reached. This means development of a sampling technique(s) which will give reliable estimates of the population present on a given unit area at some point in time.

Other than the work of Raney et al. (1970), little data exists concerning estimates of pecan weevil populations based on information obtained by any of the current sampling techniques. Since the results of the sampling studies conducted in 1972 and 1973 indicated that the adult emergence traps might be the technique of choice for sampling pecan weevil populations, a study was undertaken to develop prediction equations to estimate the pecan weevil population in a tree on a given date from the number of weevils collected from emergence traps beneath the tree.

Materials and Methods

In the study, data obtained from the 1972 and 1973 sampling studies were used. The total pecan weevil population constituted those weevils collected by all the sampling techniques on each sampling date on each of 10 pecan trees of the "Western" variety (Chapter II). The trap data represented the weevils collected by 12 emergence traps under each test tree on each sampling date.

A multiple regression program was fitted to the data. The model used was:

$$Y_{ij} = b_o + T_i + b_1 D_j + b_2 X_{ij} + b_3 D_j^2 + b_4 X_{ij}^2 + b_5 D_j X_{ij} + E_{ij}$$

where

Y_{ij} = the total number of pecan weevils collected from the ith tree on the jth sampling date

T_i = effect due to the ith tree

D_j = number of days from the 1st sampling date

X_{ij} = number of weevils collected from 12 emergence traps under the ith tree on the jth sampling date

E_{ij} = random error associated with Y_{ij}.

Thus, given the appropriate values for b's, the predicted number of pecan weevils ($\hat{Y}$) can be obtained for a given tree (T), with a trap value (X), and a sampling date (D). The b's in the foregoing equation were the least-squares solutions to the normal equations.

In the earlier sampling studies, it was observed that pecan weevils could be collected on the outside of emergence traps; therefore, some prediction equations were built from trap data which utilized the weevils collected both inside and outside of the emergence traps. In Table 8, the models A, A', C and C' represent equations built from trap data based on weevils captured both inside and outside the traps. The models B, B', D, and D' utilized trap data based only on weevils captured inside the traps.

Also in the earlier sampling studies, it was observed that later in the pecan weevil season after peak emergence, movement of pecan weevils occurred into the test trees from the border trees. Due to this phenomenon, it was felt that estimates based on trap data late in the season might be biased; therefore, prediction equations were developed from data collected early in the season presumably prior to any dispersal. To separate the sampling dates as to early season or late season and to avoid bias on the part of the experimenter in making this separation, arbitrary criteria were used to separate the early sampling dates as follows: all dates were included after the date one weevil was trapped under any tree and all dates were excluded after the date 10 or more weevils were trapped under any tree. In Table 8, the models A, B, C, and D represent equations built from early season data and models A', B', C', and D' represent equations built from data collected over the entire sampling season.

The residual mean square (RMS) was used for the experimental error. It was derived in the following manner:

$$RMS = (TSS - SSD - SST - SSX - SSX^2 - SSXD)/d.f.$$

Table 8. --Prediction equations for estimating numbers of pecan weevils. Stillwater, Oklahoma, 1972-1973.

Model[a]	Season	Trap Data	b_0	b_1	b_2	b_3	b_4	b_5	R^2
					1972				
A	Early[b]	Inside + Outside	-0.960	0.310	0.308	-0.009	-0.001	0.090	0.94
A'	Entire	Inside + Outside	-2.000	0.499	-7.141	-0.006	-0.017	0.382	0.87
B	Early[b]	Inside	1.650	-0.244	-10.778	0.017	-0.306	0.863	0.78
B'	Entire	Inside	-6.100	0.933	-3.062	-0.011	-0.053	0.449	0.72
					1973				
C	Early[c]	Inside + Outside	9.083	-0.207	-0.354	0.016	0.134	0.211	0.75
C'	Entire	Inside + Outside	11.568	-0.399	-0.218	0.016	-0.109	0.266	0.71
D	Early[c]	Inside	14.186	-1.050	-2.323	0.054	0.353	0.349	0.58
D'	Entire	Inside	13.286	-0.691	-1.333	0.036	-0.343	0.450	0.55

[a] Fitted equations are of the form $Y_{ij} = b_o + T_i + b_1 D_j + b_2 X_{ij} + b_3 D_j^2 + b_4 X_{ij}^2 + b_5 D_j X_{ij}$.

[b] Early season data in 1972 included sampling dates August 3, 1972 - August 27, 1972.

[c] Early season data in 1973 included sampling dates August 11, 1973 - September 2, 1973.

where

TSS = total sum of squares

SSD = sum of squares for days

SST = sum of squares for trees

SSX = sum of squares due to linear effect for trap (X)

SSX^2 = sum of squares due to quadratic effect for trap (X^2)

SSXD = sum of squares due to linear effect for trap (X) by linear effect for days (D)

d.f. = degrees of freedom .

Results and Discussion

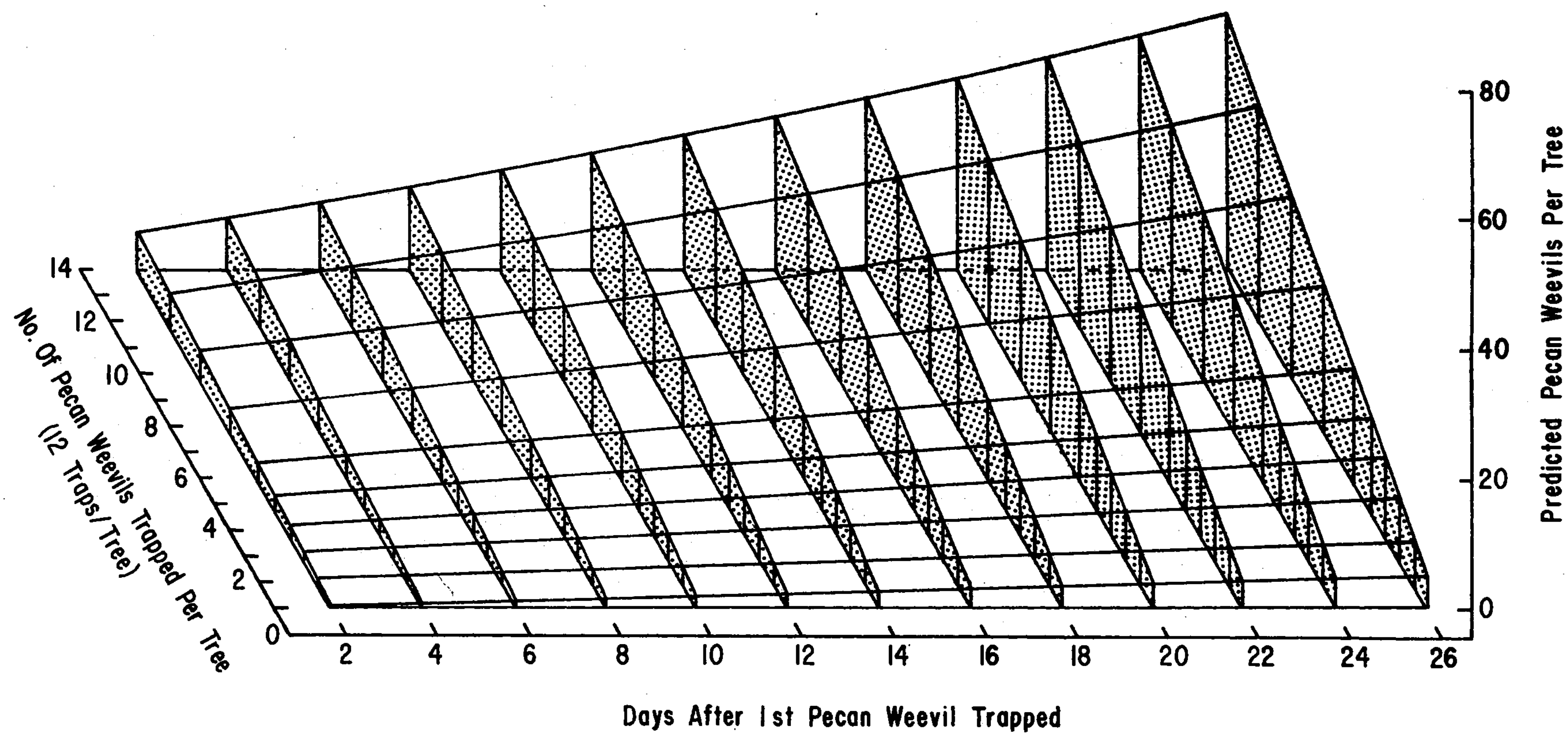
The square of the multiple correlation coefficient, R^2, is the proportion of the sum of squares that are attributable to regression. Since model A and model C had the largest R^2 values for 1972 and 1973, respectively (Table 8), these models were evaluated to determine their effectiveness for predicting pecan weevil populations.

The number of pecan weevils predicted by model A was compared to the actual number of pecan weevils collected on each early season sampling date in 1973. Twelve dates fell into the early season category in 1973 with 10 trees sampled on each date thus giving 120 data points. It was found that 86 or 71.7% of the observed data points fell within the predicted 95% confidence intervals for model A. The confidence intervals were set according to the procedures of Draper and Smith (1966). In general, the range of the confidence intervals was ca. 30 weevils.

Figure 5 depicts the 3-dimensional response surface generated by model A for the "average" pecan tree ($T_i = 0$). As the season

Figure 5. Three-dimensional response surface depicting the number of pecan weevils predicted from various trap values on different sampling dates on the "average" pecan tree. Stillwater, Oklahoma, 1972.

1972 Model A



80
60
40
20
0
Predicted Pecan Weevils Per Tree
14
12
10
8
6
4
2
0
No. Of Pecan Weevils Trapped Per Tree
(12 Traps/Tree)
2
4
6
8
10
12
14
16
18
20
22
24
26
Days After 1st Pecan Weevil Trapped

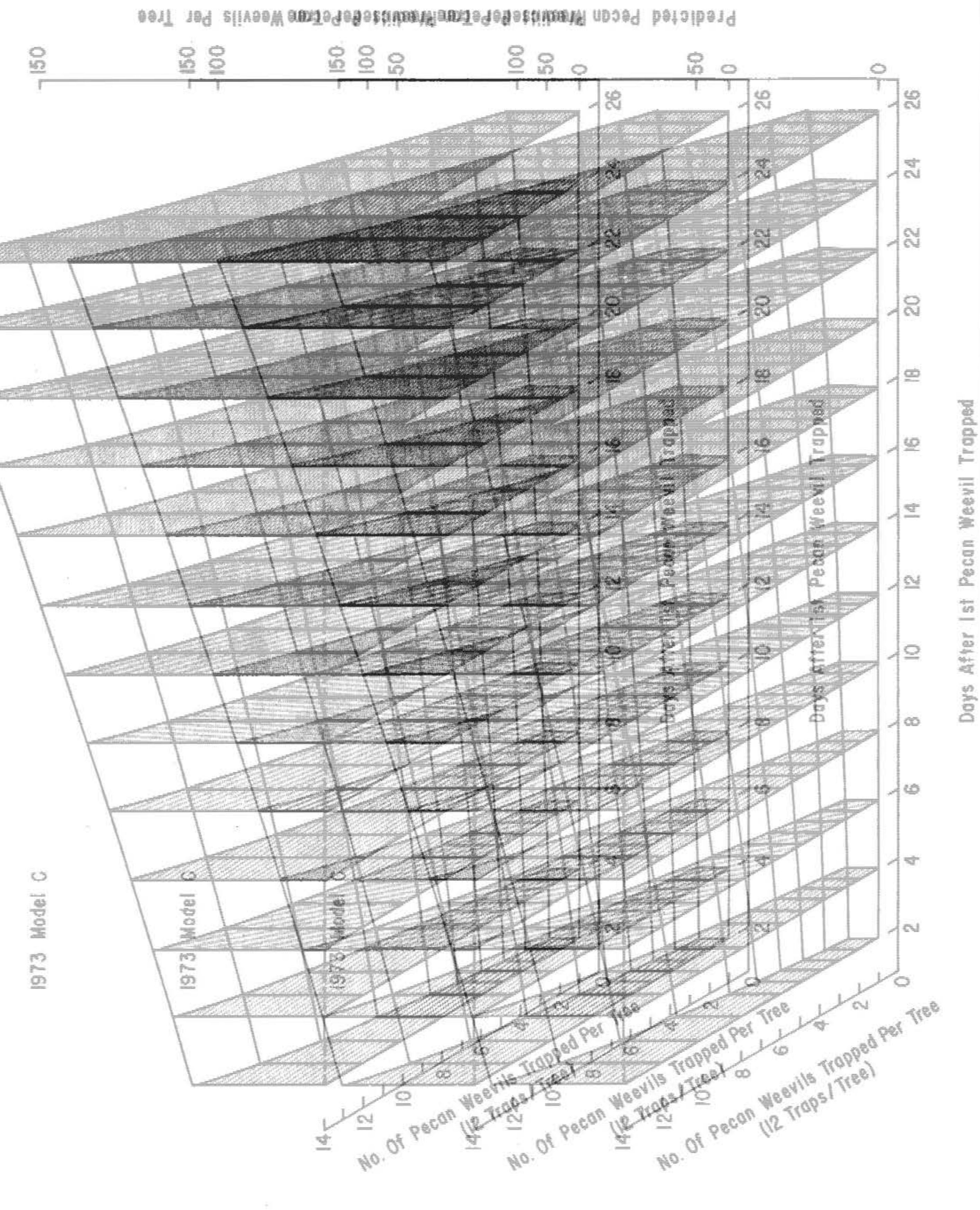
progressed, the number of pecan weevils predicted from any trap value increased at an increasing rate. For example if six weevils were trapped late in the season, more weevils would be expected to be in the tree than if six weevils were trapped earlier in the season.

Model C then was tested to determine how the predicted values compared to the actual number of pecan weevils collected on the early season sampling dates in 1972. Thirteen dates fell into the early season category in 1972; however, since model C was built from data on 12 dates, the data for August 27, 1972 could not be tested. Thus 120 data points from 1972 were compared with the predicted values from model C. It was found that 114 or 95% of the observed data points fell within the predicted 95% confidence intervals for model C. Again the range on the confidence intervals was ca. 30 weevils.

Figure 6 depicts the 3-dimensional response surface generated by model C for the "average" pecan tree ($T_i = 0$). The response surface is similar to that generated by model A. More weevils appeared earlier in the season in 1973 thus accounting for the larger numbers of predicted weevils. Again as the season progressed, the number of pecan weevils predicted from any trap value increased at an increasing rate.

To explain this phenomenon is difficult. Perhaps as the season progressed, weevils dispersed into the test trees creating larger weevil populations than expected from the related trap values. However, since models A and C were built from early season data presumably prior to any dispersal, this explanation seems somewhat unlikely.

Figure 6. Three-dimensional response surface depicting the number of pecan weevils predicted from various trap values on different sampling dates on the "average" pecan tree. Stillwater, Oklahoma, 1973.


1973 Model C
Predicted Pecan Weevils Per Tree
Days After 1st Pecan Weevil Trapped
No. Of Pecan Weevils Trapped Per Tree
(12 Traps/Tree)

When the 95% confidence intervals were built for testing the effectiveness of models A and C, the effects due to the ith tree (T_i) were incorporated into the calculations. Thus by knowing which of the 10 trees was being tested, the precision in predicting the weevil populations by these models was increased. If attempts are made to utilize the models in field situations for estimating pecan weevil populations, the values for T_i would be unavailable due to lack of information about the inter-tree variation in populations in most orchards. An approach that might be taken would be to use the models for the "average" pecan tree ($T_i = 0$). In this regard, caution must be expressed because the sampling studies conducted in 1972 and 1973 indicated that the inter-tree variation in pecan weevil populations was large.

Summary

The data obtained by sampling studies during 1972 and 1973 (Chapter II) were used to develop equations for predicting the number of pecan weevils in a tree from the number of pecan weevils trapped beneath that tree on a given date. Two of the models then were tested to determine their effectiveness in estimating weevil populations.

When the population estimates obtained from the model built from the early season data in 1972 (model A) were compared to the actual populations found in the trees in 1973, it was found that 71.7% of the observed values in 1973 fell within the 95% confidence intervals for the predicted values. When similar comparisons were made utilizing the model built from early season data in 1973 (model C), 95% of the observed population values in 1972 fell within the confidence intervals for the predicted values. Three-dimensional response surfaces generated from the models were similar and revealed that as the season progressed the number of pecan weevils predicted from any trap value increased at an increasing rate.

González (1970) depicted a pest management program as being analogous to a house with sampling techniques serving as part of the foundation along with economic thresholds. Although preliminary, this study indicated that the emergence trap technique appeared promising as a device for estimating pecan weevil populations. Should further studies verify these findings, the technique may prove valuable for incorporation into a pest management program for pecan weevils once economic thresholds are developed.

CHAPTER IV

PECAN WEEVIL: DETERMINATION OF THE RELATIONSHIPS BETWEEN CERTAIN PHYSICAL PARAMETERS AND ADULT EMERGENCE

Early workers on the biology of the pecan weevil established that times of adult emergence from the soil varied from year to year, but usually occurred in late summer or early fall. Moznette et al. (1931) were the first researchers who attempted to associate a climatic phenomenon (precipitation) with the onset of weevil emergence. Price (1939), Hinrichs (1948), Nickels (1950), and Dupree and Beckham (1953) observed that heavy rainfall stimulated emergence. Dupree and Bissell (1965) reported that over a 10 year period peak emergence appeared to occur in late August during years of normal rainfall. The years in which variations from this pattern occurred were associated with periods of drought preceding emergence.

Although the early literature linked weevil emergence with rainfall, much of the information was speculative rather than based on quantitative data. Hinrichs and Thomson (1955) were the first to gather empirical data concerning amounts of rainfall and corresponding weevil emergence. Over a span of four years, in Oklahoma, they found that emergence occurred earlier in the season following rainfall in late July and early August. Data by Raney et al. (1970) confirmed that of Hinrichs and Thomson and they stated "weevil emergence increased 3-4 days after a 1-2 in. rainfall." Harp (1970) studied rainfall and pecan weevil emergence at two locations in Texas. He reported that rainfall may influence emergence but was not convinced that emergence was totally moisture dependent.

Due to the inconsistency of early research, studies were undertaken in 1972 and 1973 to characterize the physical environment in an uncultivated orchard and to evaluate the effects that parameters such as temperature (soil and air), relative humidity, rainfall, and soil moisture had on pecan weevil emergence.

Materials and Methods

These studies were conducted in conjunction with the sampling studies during 1972 and 1973. Since the adult emergence traps could be checked daily regardless of the weather conditions, they were utilized to monitor pecan weevil emergence from the soil. The location of the test trees, the arrangement of the emergence traps beneath the trees, and the procedure followed in checking the traps were described in Chapter II.

The soil analysis conducted by the Department of Agronomy, Oklahoma State University, revealed that the soil type found in the experimental plot was a Port Loam. The particle size analysis and % organic matter are shown in Table 9.

1972 Experiment

Temperature, relative humidity, rainfall, and soil moisture were measured in 1972. The temperature and relative humidity were

Table 9. --Soil analysis data from experimental plot showing particle size analysis and percent organic matter. Stillwater, Oklahoma, 1972-1973.

Sample Depth (inches)	% Organic Matter	Particle Size Analysis			
		% Sand	% Silt	% Clay	Texture
0-3	1.79	52	28	20	Loam
3-6	0.84	49	29	20	Loam
6-9	0.59	44	36	20	Loam

recorded daily by a hygrothermograph located in a weather station at the center of the experimental plot. Rainfall data were obtained from three rain gauges (Fig. 7).

Since most pecan weevils can be found in the soil from 3 to 9 in. in depth (Gill 1924; Leiby 1924; Moznette et al. 1931; Hinrichs and Thomson 1955), a soil sample of 9 in. was taken daily beneath each of five trees to assess the influence various amounts of rainfall had on soil moisture. A soil sampling probe was used to collect the soil samples with the even- and odd-numbered trees sampled on alternate days. Samples were taken each day between 1500-1700 h. Each soil sample was divided into three 3 in. samples as follows: (a) surface to 3 in.; (b) 3 to 6 in.; and (c) 6 to 9 in. Hereafter, the samples will be referred to as 3, 6, and 9 in. samples, respectively. After collection, the divided samples (ca. 40 g each) were transferred to air-tight containers for transportation to the laboratory. The samples were weighed prior to drying in an oven at 105°C. After drying the samples were weighed again and % soil moisture was determined by the following formula:

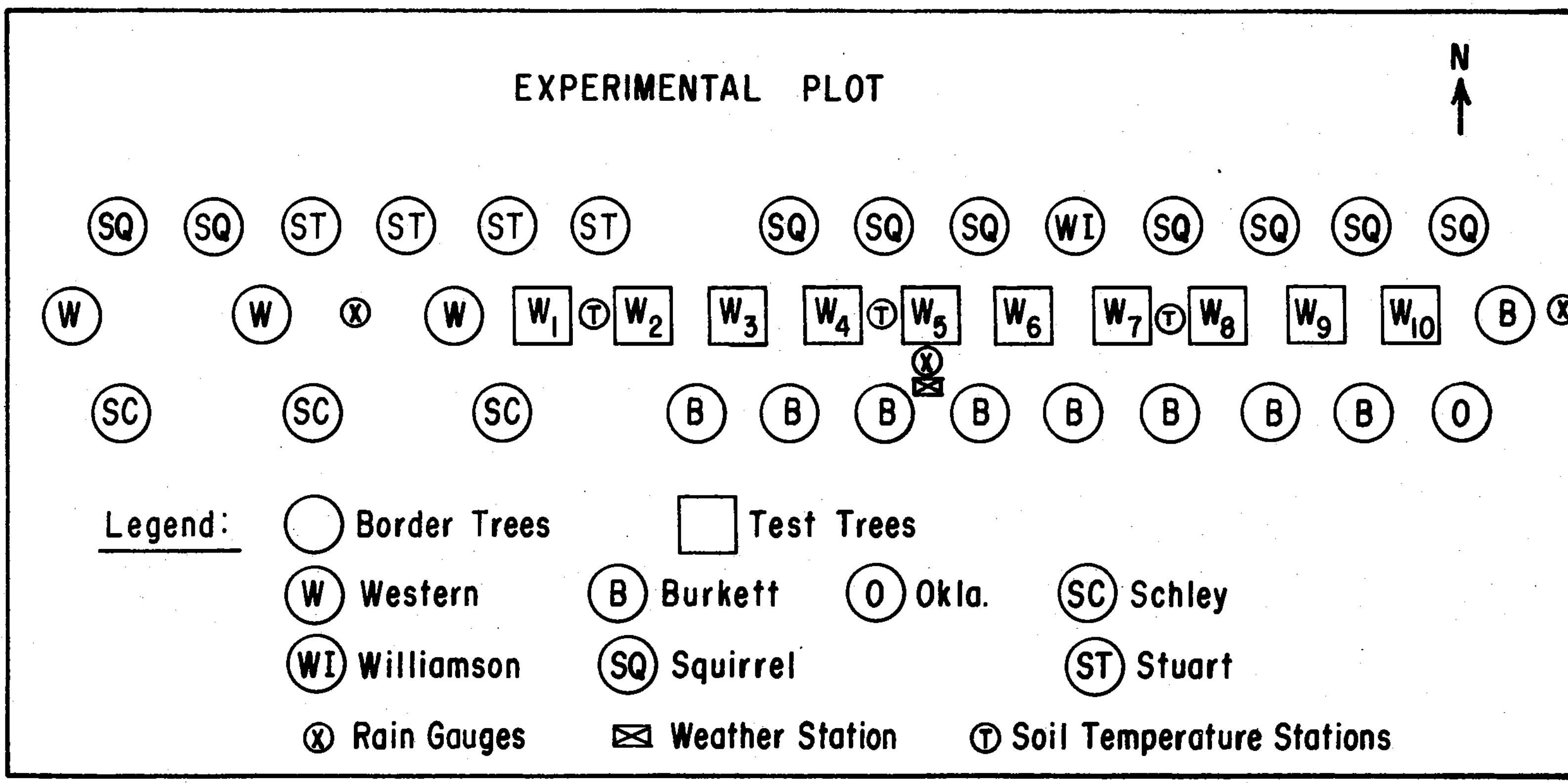
$$\%\ \text{soil moisture} = \frac{\text{wt. of wet} - \text{wt. of dry}}{\text{wt. of dry}} \times 100 \quad .$$

Mean % soil moisture for each day was derived by averaging the five samples from each depth.

1973 Experiment

In 1973 data was obtained on soil temperature in addition to those parameters measured in 1972.

Figure 7. Diagram of experimental plot showing location of test pecan trees and placement of weather station, rain gauges, and soil temperature stations. Stillwater, Oklahoma, 1972-1973.


EXPERIMENTAL PLOT
N
SQ SQ ST ST ST ST SQ SQ SQ WI SQ SQ SQ SQ
W W X W W1 T W2 W3 W4 T W5 W6 W7 T W8 W9 W10 B X
X
SC SC SC B B B B B B B B O
Legend:
Border Trees
Test Trees
W Western
B Burkett
O Okla.
SC Schley
WI Williamson
SQ Squirrel
ST Stuart
X Rain Gauges
Weather Station
T Soil Temperature Stations

Soil temperature measurements were taken daily between 1500-1700 h at three sample sites in the experimental plot (Fig. 7). Probes were buried at each site at depths of 3, 6, and 9 in., and a portable YSI Telethermometer® [1/] was used to measure the temperature at each depth. The mean daily soil temperature at each depth was obtained by averaging the readings from the three sample sites.

Results

1972 Experiment

The results of the 1972 experiment are shown in Fig. 8. Although the study commenced August 1, few weevils were captured during the first two weeks. Peak emergence of adult pecan weevils occurred on August 27 following a 1.2 in. rain on August 24. Even though the emergence traps were checked through October, no further peaks of emergence occurred.

The moisture content at all sample depths increased following the August 24 rainfall, and after the rainfall of August 29 - September 1, remained at a fairly high level. As expected, immediately following rainfall the 3 in. sample was the first to show increases in soil moisture, followed by the 6 in. and 9 in. samples, respectively. The moisture content at the two lower depths did not fluctuate as much between periods of rainfall as did the 3 in. sample.

In general, the daily high temperatures for the days of peak emergence (August 27-29) were lower than the daily high temperatures

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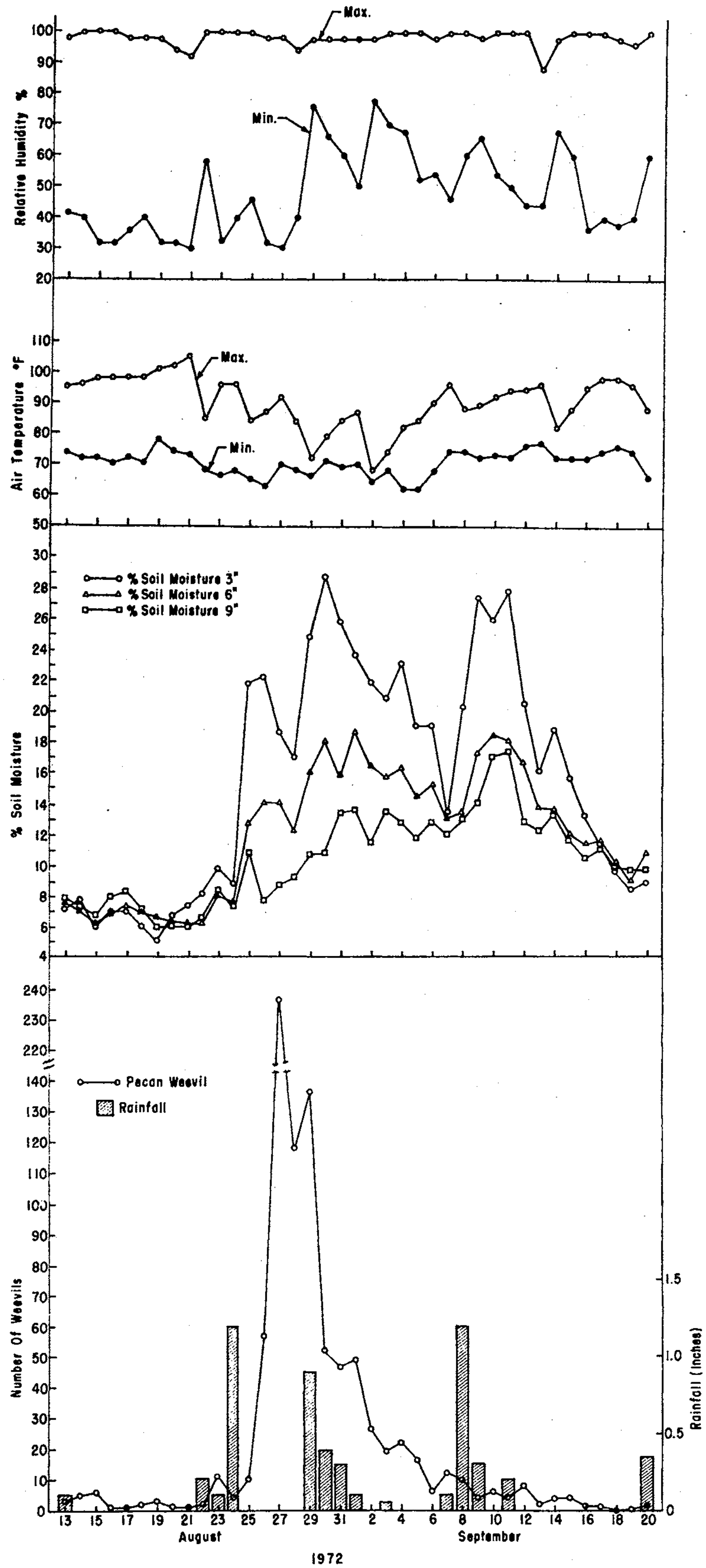
[1/] Yellow Springs Instrument Co., Inc. Yellow Springs, Ohio 45387, U.S.A.

Figure 8. Results of the 1972 study on adult pecan weevil emergence. The number of weevils shown represents the total collected from 120 emergence traps beneath the test trees. The % soil moisture represents the daily mean at each sample depth. The temperature and relative humidity represent the daily maximum and minimum readings. Stillwater, Oklahoma, 1972.



Max.
Min.
Relative Humidity %
100
90
80
70
60
50
40
30
20
Max.
Min.
Air Temperature °F
110
100
90
80
70
60
50
% Soil Moisture 3"
% Soil Moisture 6"
% Soil Moisture 9"
% Soil Moisture
30
28
26
24
22
20
18
16
14
12
10
8
6
4
Pecan Weevil
Rainfall
Number Of Weevils
240
230
220
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
Rainfall (Inches)
1.5
1.0
0.5
0
13
15
17
19
21
23
25
27
29
31
2
4
6
8
10
12
14
16
18
20
August
September
1972

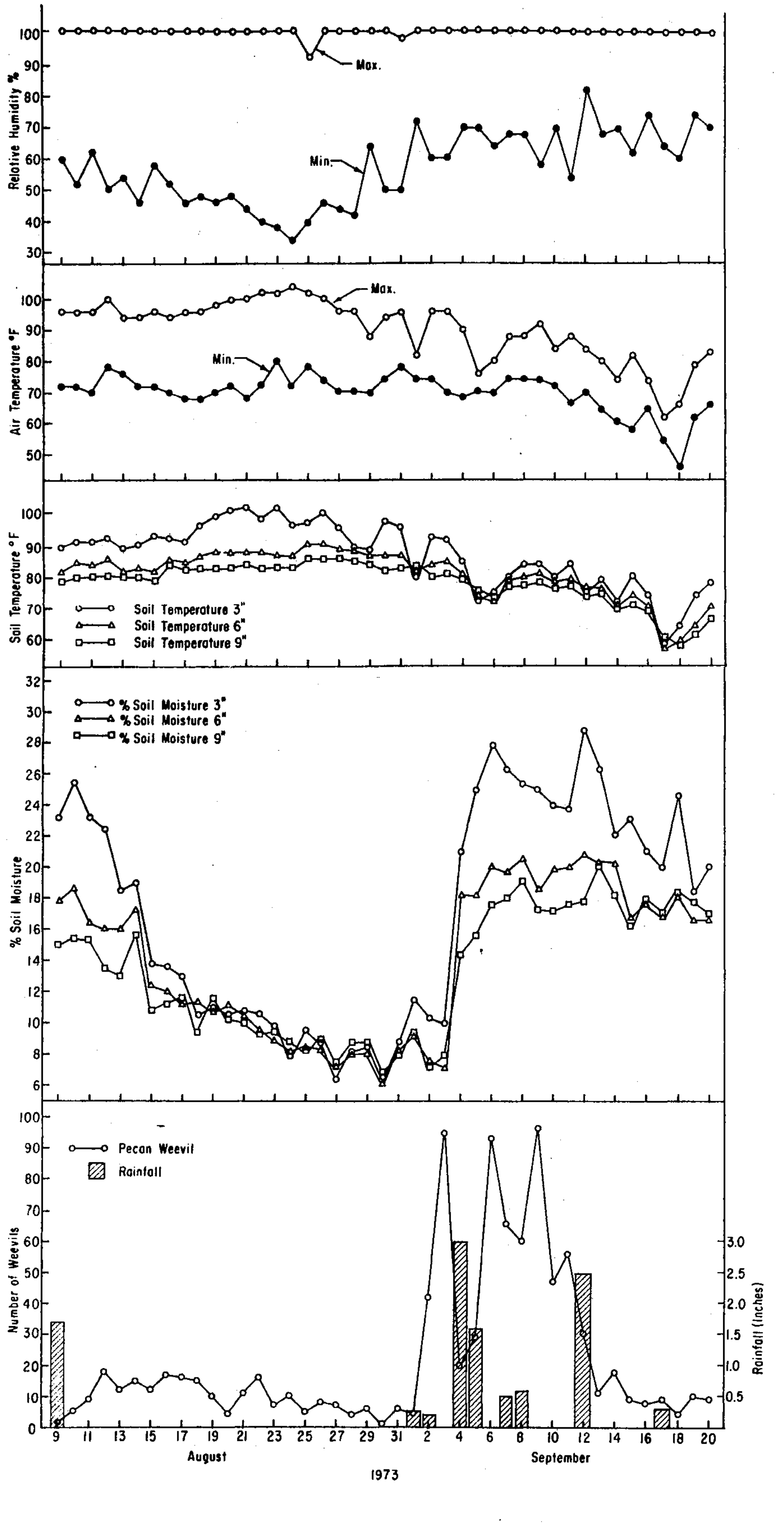
for the other days during the emergence period. There did not appear to be any correlation between weevil emergence and relative humidity.

1973 Experiment

The results of the 1973 experiment are shown in Fig. 9. Again, even though the study commenced August 1, few weevils emerged early in the season. A 1.7 in. rain occurred August 9, which increased the soil moisture at all sample depths; however, only low numbers of weevils emerged. The first peak of emergence occurred September 3. A combined total of 0.5 in. of rainfall occurred on September 1 and 2; however, only the 3 in. sample showed any increase in soil moisture. Heavy rains on September 4 and 5 increased the soil moisture at all sample depths. These rains appeared to depress emergence, because another peak of emergence occurred on September 5 when the rainfall halted. The same phenomenon occurred to a slighter extent on September 7 and 8. Rainfall on these dates appeared to suppress emergence, followed by the third peak on September 9 when the rainfall subsided. Again, the traps were checked through October; however, no further peaks of emergence occurred.

In 1973 as in 1972, smaller amounts of rainfall were accompanied by increases in moisture content in the 3 in. sample near the surface. The rainfall of August 9 and September 4 were sufficient to affect the soil moisture at the 9 in. depth. Following the rainfall on the latter date, the moisture content of the soil remained relatively high throughout the remainder of the experiment.

Figure 9. Results of the 1973 study on adult pecan weevil emergence. The number of weevils shown represents the total collected from 120 emergence traps beneath the test trees. The % soil moisture and soil temperature represent the daily mean at each sample depth. The air temperature and relative humidity represent the daily maximum and minimum readings. Stillwater, Oklahoma, 1973.


Relative Humidity %
Max.
Min.
Air Temperature °F
Max.
Min.
Soil Temperature °F
Soil Temperature 3"
Soil Temperature 6"
Soil Temperature 9"
% Soil Moisture
% Soil Moisture 3"
% Soil Moisture 6"
% Soil Moisture 9"
Number of Weevils
Pecan Weevil
Rainfall
Rainfall (Inches)
August
September
1973

In general, the soil temperatures in the experimental plot were lower during the peak emergence periods than earlier in the season. Again, no correlation appeared to exist between air temperature or relative humidity and weevil emergence.

Discussion

The results of the 1972 experiment agreed to some extent with that of earlier researchers. The emergence pattern following rainfall agreed with the findings of Hinrichs and Thomson (1955) and Raney et al. (1970) under Oklahoma conditions; however, only one peak of emergence occurred in the present study. They observed peaks after each rainfall.

Prior to the rainfall of August 24 the soil in the orchard was extremely compact, making it difficult to penetrate for a soil sample. Few weevils emerged before this rainfall, probably due to the soil compaction.

In 1973 few weevils emerged following the rainfall of August 9, although the soil moisture levels were higher than the soil moisture levels encountered in 1972 when peak emergence occurred. The first significant peak of emergence occurred on September 3 following slight amounts of rainfall on the two previous days. This rainfall did not increase the moisture content to the levels encountered earlier in the season. The soil became compact subsequent to the August 9 rainfall and did not loosen until the rainfalls of September 1 and 2. As the data in Fig. 9 indicate, few weevils emerged during this time period. This data, along with the emergence pattern during early season in 1972, support earlier researchers (Hinrichs and Thomson

1955) who observed that emergence was prevented due to dry compact soil. VanCleave and Harp (1971) concluded that the most critical point in the pecan weevil's life cycle involved its emergence from the soil, because they observed that a majority of caged adult weevils were dead near the soil surface with their proboscis pointed upward.

Harp (1970) hypothesized that rainfall suppressed pecan weevil emergence. The 1973 results somewhat conform his hypothesis because rainfall on September 4, 5, 7, and 8 coincided with drops in emergence.

Several researchers, the most recent being Criswell (1974), found that pecan weevils prefer to oviposit after the pecan kernel becomes firm. Harp (1970) suggested that the weevils had evolved in perfect synchrony with the fruit maturity of its host and emerged each year accordingly. Perhaps selection has favored those weevils that emerge when the nuts are suitable for oviposition. During the two years of these studies a majority of the pecan weevils did emerge at the time the nuts entered the firming stage.

Summary

Early data collected over a wide geographical area (Georgia, Oklahoma, and Texas) suggested a correlation between rainfall and the onset of pecan weevil emergence. Of the physical parameters measured in these studies, rainfall and resultant soil moisture had the most important effect on weevil emergence by their influence on soil compaction. Weevil emergence was not completely dependent on soil moisture because pecan weevils emerged throughout August and September with peak emergence occurring the last week in August and the first week in September. Rainfall did coincide with the times of peak emergence, but rainfall early in the season (especially 1973) was not followed by emergence of large numbers of pecan weevils.

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VITA

David John Boethel

Candidate for the Degree of

Doctor of Philosophy

Thesis: PECAN WEEVIL, CURCULIO CARYAE (HORN): COMPARISON OF SAMPLING TECHNIQUES, ESTIMATION OF POPULATIONS, AND DETERMINATION OF THE RELATIONSHIPS BETWEEN CERTAIN PHYSICAL PARAMETERS AND ADULT EMERGENCE

Major Field: Entomology

Biographical:

Personal Data: Born in Hallettsville, Texas, January 3, 1946, the son of Ludwig C. and Helen O. Boethel.

Education: Graduated from Weimar Public School, Weimar, Texas, May, 1964; received a Bachelor of Science degree from Texas A & M University, College Station, Texas, May, 1968; received a Master of Science degree from Texas A & M University, College Station, Texas, January, 1970; completed requirements for the Doctor of Philosophy degree at Oklahoma State University, Stillwater, Oklahoma, July, 1974.

Professional Experience: Technical Assistant, Department of Entomology, Texas A & M University, College Station, Texas, 1966-1968, NDEA Traineeship, Department of Entomology, Texas A & M University, College Station, Texas, 1968-1970; Captain, Medical Entomologist, Medical Service Corps, U. S. Army, Ft. McPherson, Georgia, 1970-1972; Graduate Research Assistant, Department of Entomology, Oklahoma State University, Stillwater, Oklahoma, 1972-1974.

Organizations: Alpha Zeta; American Registry of Professional Entomologists; Entomological Society of America; Phi Eta Sigma; Phi Kappa Phi; Sigma Xi.