DEVELOPMENT AND GIRDLING ACTIVITY OF THE SOUTHWESTERN CORN BORER, *Zeadiatraea grandiosella* (Dyar), RELATED TO CORN HARVESTING LOSSES

By

DONALD L. BAILEY

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Dean of the Graduate School

PREFACE

Several million dollars have been sacrificed to the southwestern corn borer, Zeadiatraea grandiosella (Dyar), through its damage to corn since the borer's introduction into this country. Little work has been done to determine the relation between development and girdling activity of the pest to yield loss when a mechanical harvester is used. In this mechanized age, hand harvesting of corn has largely disappeared. It is in mechanical harvesting that the greatest loss is suffered due to stalk girdling by the borer.

After conferring with Dr. R. R. Walton, Professor, Department of Entomology, and Mr. K. D. Arbuthnot, Entomology Research Division, United States Department of Agriculture, now deceased, the writer decided to initiate a study to determine harvesting losses with special emphasis on the best time to harvest in order to reduce these losses to a minimum.

Data were taken at Paradise Research Station during the August 1961 to March 1962 period from corn planted on two different dates.

Valuable assistance was given by several individuals and organizations at Oklahoma State University to whom I

wish to express my appreciation. Mr. K. D. Arbuthnot helped initiate the study, supervised field research, and assisted in taking some of the data. Dr. R. R. Walton, who served as my committee chairman, and Dr. Harvey Chada, Entomology Research Division, United States Department of Agriculture, gave valuable advice in preparation of the manuscript. Dr. D. E. Howell, head of the Department of Entomology, and Dr. J. S. Brooks, Department of Agronomy, gave valuable advice on technical problems. Monetary assistance and transportation was provided by the Entomology Research Division, United States Department of Agriculture, and by the Entomology Department, Oklahoma State University. I also wish to express appreciation to my wife, Sheron, for assisting in typing and proofreading, and to Mrs. Grant Kinzer for typing the final manuscript.

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INTRODUCTION

The southwestern corn borer, *Zeadiatraea grandiosella* (Dyar), is a major pest of corn in the southwestern United States and probably causes more damage to corn than any other insect species in Oklahoma. It is in the genus *Zeadiatraea*, transferred there by Box (1955) from the original genus *Diatraea*. This insect is a lepidopteran in the family Crambidae.

This pest was first reported in Oklahoma in 1930 from two counties in the Panhandle, and by 1953 the infestation had spread to every county in the State. It was earlier thought to be a tropical or subtropical species; however, the southwestern corn borer has become adapted to a colder climate in the past half century.

In 1942 losses from southwestern corn borer damage in the southwestern United States were estimated at two million dollars. By 1951 this estimate had risen to 22 million. Due in large part to this heavy loss, the acreage annually planted to corn in Oklahoma has fallen sharply in the last few years.

A satisfactory control for the southwestern corn borer has not been discovered. A few chemical compounds have been found to be effective in controlling the borer;

however, the cost of the insecticide and the expense of labor and application equipment usually make this uneconomical for control purposes. Cultural control methods are the most economical at this time. These include early planting, increase of fertilizer, early harvesting, and plowing under stubble in the fall. Each method will reduce the borer population, but none of them affords completely satisfactory control.

One of the most important types of damage by borers to corn is stalk girdling. This type of damage was the reason for conducting an experiment to determine the loss suffered when borer-infested corn is mechanically harvested. It was believed that some basis could be established for determining the most satisfactory time to harvest corn mechanically so as to reduce to a minimum the losses caused by borer-lodged plants.

REVIEW OF LITERATURE

Synonomy

Dyar (1911) first described the southwestern corn borer and gave it the name *Diatraea grandiosella*. Before this description, it was referred to as other species of *Diatraea*. Many references were made to this insect in the United States under the name *Diatraea lineolata* (Walker). Dyar and Heinrich (1927) stated that the insect referred to could not be *D. lineolata* because that species was not present in the United States, but occupied a more southern area. Box (1955) removed the southwestern corn borer from *Diatraea* and placed it in a new genus *Zeadiatraea*. Changes were made on the basis of the shape of the genitalia.

Confusion with other species of the Diatraea complex

The close resemblance of the several species of the *Diatraea* complex makes positive larval identification of species very difficult. The southwestern corn borer may especially be confused with the neotropical corn stalk borer, *Z. lineolata* (Walker); the sugar cane borer, *Diatraea saccharalis* (Fabr.); and the southern corn stalk borer, *D. crambidoides* Grote. Peterson (1948) stated that his key to the larvae of Z. grandiosella, D. saccharalis, and D. crambidoides was not always dependable due to variation within a species. Z. lineolata is not known to be present in the United States. D. crambidoides is a problem on corn in eastern and southeastern United States, but its western range is limited, having been reported only twice in Kansas. It is doubtful if its range crosses that of Z. grandiosella at this time. D. saccharalis is limited to the Gulf Coast area of Louisiana, Texas, and Florida.

Description

Davis et al. (1933) gave a general description of the four life stages of Z. grandiosella. They described the eggs as being translucent white at oviposition. After about 24 hours they become creamy white with three parallel orange-red bars dividing them into four more or less equal parts, giving them an orange-colored appearance. About 24 hours before hatching, the head and thoracic plates become visable through the chorion. The eggs are usually laid in a mass, overlapping shingle fashion, but occasionally are deposited singly. The larvae escape the eggs through lateral slits.

Both summer and winter form larvae of the southwestern corn borer occur. The summer form larvae are milky white with distinct brownish-black spots over the body. The head capsule is very dark except immediately after molting when it is a pale yellowish-brown. The summer form usually has six larval instars and finally loses its spots when it molts to the immaculate winter form. This form spends the winter in diapause as an inactive, butter-yellow larva.

The pupae are creamy white when pupation begins, but attain a dark-brown color after 24 hours. Sexing of the pupae may be done by noting the suture dividing the last abdominal sternite in the female which is absent in the male.

Davis et al. (1933) described the adult as being a light straw-colored, dull white moth. The hind wings are broad, semicircular in outline, and slightly lighter-colored than the fore wings. The wings are held folded close over the body when at rest. The labial palpi form a beak-like structure which extends forward and downward.

Distribution in the United States

The southwestern corn borer entered the United States at some unknown time prior to 1930. The first report in the United States was in Arizona (Todd and Thomas, 1930), but it probably entered this country at several points along the Mexican border. They stated that this pest was probably present in the United States at least 10 years prior to 1930.

The borer spread rapidly after it was established in this country. Davis et al. (1933) reported Z. grandiosella occupied the southeastern corner of Arizona, the southeastern two-thirds of New Mexico, most of the Panhandle and Big Bend areas of Texas, and two western counties in the Oklahoma Panhandle. It was also reported in southeastern Colorado that year, but has not been recorded from there since that date. By 1953 it had extended its range to the eastern border of Oklahoma. During this time it had pushed northward to infest corn in all of Kansas except small areas in the northwestern and northeastern parts of the State. In 1943 (Tate and Bare, 1945) the southwestern corn borer was present in three counties in south central Nebraska, but has not been reported from that state since 1945.

In 1949 Walkden and White (1950) reported *Z. grandiosella* for the first time in Arkansas. It was first found in Missouri in 1950 (Walkden and White, 1951). In Texas, *Z. grandiosella* has been reported in counties adjoining counties occupied by *D. saccharalis* (Anonymous, 1955 b).

The northward spread of the southwestern corn borer was very fast, but the eastward spread was slow. This indicates that the strong winds from the south in the summer tend to help the northward spread, while the eastward movement is mainly dependent on the flights of the moths. To date this pest has been reported from 11 southwestern and central states. The infested area now extends from Arizona and New Mexico, eastward across Texas, Oklahoma, and Kansas, into Louisiana, Arkansas, Mississippi, and Missouri.

Seasonal history

The life cycle of the southwestern corn borer is not complicated but is rather unique. A complete account of its life cycle in Arizona was presented by Davis et al. (1933), which includes the following information. The immaculate larvae, which overwinter in the crowns of corn stubble, pupate in late April and adult moths emerge in about 11 days. Mating usually takes place the first night, and oviposition begins the second night. Eggs are laid singly or in masses, averaging about five per cluster in the field and about nine under laboratory conditions. The incubation period is five days during most of the season. Most hatching occurs during the morning daylight hours. Newly-hatched larvae are active and begin to feed soon after hatching. Most of them crawl to the tender folded leaves of the bud or growing point. The third or early fourth instar larvae begin to leave the bud and migrate down the plant, tunneling into the stalk and boring downward. They may tunnel to the outside occasionally, crawl down the stalk a short distance, and bore in again. The sixth instar larvae finally molt to become pupae approximately one month after hatching. Moths emerge in late June and early July to mate and lay eggs for the second generation. The second generation larvae follow the same pattern of development except that some pupate to produce a partial third generation in August and September, while the remainder tunnel to the crown of the plant and prepare cells in which to pass the winter. Most of the third generation larvae do not survive to pass the winter because the plant by this time is too tough for them to penetrate, or cold weather sets in before they are fully mature.

Walton and Bieberdorf (1948 a) reported the length of the life stages of Z. grandiosella in Oklahoma as follows: eggs, 5-6 days; larvae, 20-35 days; pupae, 8-10 days; and adults, 5 days. The bulk of the first generation borers appear in June; however, they may begin to show up late in May. These workers reported the length of the life cycle in Oklahoma as 38-56 days.

Damage to host plants

Several hosts have been reported for the southwestern corn borer. Davis et al. (1933) listed the hosts as corn, grain sorghums, sugarcane, broomcorn, and Johnson grass. Walton and Bieberdorf (1948 a) added Sudan grass to this list of host plants, and Painter (1955) reported the borer on teosinte in Guatemala. Corn, however, is the favored host, and other hosts tend to extend the length of the life cycle. Gifford et al. (1961) found the length of the larval period on sorghum to be 25 to 36 days, while Walton and Bieberdorf (1948 a) found 20 to 35 days were required on corn. Rolston (1955 b) found the average length of the larval stage to be 22 days on corn and 29 days on sorghum.

The southwestern corn borer causes damage to corn in several ways. Walton and Bieberdorf (1948 a) stated that damage to corn was caused by perforation of the leaves and feeding on the terminal bud by early instars, tunneling in the stalk and ear by later instars, and girdling of the plant by borers preparing for winter. The first generation larvae perforate the leaves and cause "dead heart" by chewing into and killing the terminal bud until they reach the third or fourth instar at which time they begin tunneling toward the crown. This weakens the stalk and lessens the nutrient carrying capacity of the plant. Damage by the second generation borers is similar to the first. Just before or immediately following the construction of winter quarters in the plant crown, the borer girdles the plant. This girdling results in a major type of damage because the movement of the stalk by the wind or other force may cause the plant to lodge. If this happens before the harvesting operation, the lodged stalks may not be harvested if a mechanical harvester is used.

Harvesting the corn crop

Methods of harvesting the corn crop have undergone a marked evolution in the United States since this country was founded. Hand picking was the only method used during early development of this nation because of lack of mechanization. It was not until 1850 that the first corn picker was patented (Lyman, 1927). This was a crude machine and required many improvements. The mechanical pickers used today began their development in

1889, and in 1927 the first two-row pickers were placed on the market.

The appearance of the corn combine was possibly the greatest single advancement in mechanized harvesting. A combine for corn was first built in 1928, but did not sell due to a lack of drying equipment. Another attempt was made to produce a corn combine in 1942, but was halted by the war. It was not until 1948 that the first successful combine was built (Grimm, 1948). This machine consisted of two, two-row picker heads, a corn sheller, a 160 HP engine, and a 280-bushel grain tank mounted on an army surplus "duck" chassis. It had nine forward speeds ranging from 1.3 to 20 MPH, and operated on one gallon of fuel per acre. Four years later, J. I. Case Company made the first factory built corn combines (O'Brien, 1952). The early combines ran the entire corn plant through the cylinder, but it was found that this was unnecessary, and snapping rollers were substituted for the cutter bar, allowing the ears to pass through (Anonymous, 1955 b).

METHODS AND MATERIALS

A study to determine the effects of stalk girdling by the southwestern corn borer on grain yield when harvested with a combine was conducted during the summer of 1961 at the Paradise Research Station. The Oklahoma State University Agronomy Department provided land for the experiment, planted and cultivated the corn, and furnished a combine for harvesting. The degree of infestation and location of borers on and in the plants were determined by making periodic plant dissections between August 10 and November 14. Records were made of the progress of girdling and crop maturity for use in timing the harvest.

Texas 30 hybrid corn was planted on Vanoss loam soil on April 25 and May 19. These two planting dates were set up in two separate randomized block split-plot experimental designs. Six replicates were used in each design. Each replicate included three randomized date-of-harvest plots, and each of these contained three randomized method-of-harvest sub-plots. Sub-plots consisted of four 42-inch rows 100 feet long. Two of the four rows were used for plant dissection to study borer development and activity, and the remaining two rows were used for yield records.

Because of randomization, date-of-harvest plots occurred at different points throughout the field. This made it necessary to leave a 30-foot alley between the main plots to make each of these plots accessible. A five-foot alley was left between method-of-harvest sub-plots to allow the machine to clean out when reaching the end of the row.

Wooden stakes, labeled to indicate replicate number and date and method of harvest, were used to mark each of the 54 sub-plots within each planting.

Plant dissection

In order to follow borer development in relation to plant maturity, periodic dissections of plants were made twice weekly in each of the two plantings after August 10 until the first harvest; then dissections were made once a week. One plant for dissection was chosen at random from one of two rows within each sub-plot. After several trials of pacing the length of the 100-foot sub-plots, it was found that it took an average of 33 paces to reach the end. Thirty-three numbers were placed in a box from which one number was drawn on each dissection date. The number drawn indicated the number of paces the selected plant was from the end of the row. The first plant beyond the stopping point in one of the two rows was taken for dissection.

The plants were carried back to the laboratory for dissection. The number and location of summer and winter form larvae, instar of summer larvae, incidence of girdling, and moisture per cent of the grain were recorded for each stalk.

Basis for timing harvest

Three harvest dates for each planting were planned, each determined by moisture content of the grain. The first was to be made when moisture content was 25 per cent, the second 15 per cent, and the third made later in the season. Combine harvesters are reported to harvest effectively when grain has up to 30 per cent moisture (Miller, 1960). When dissections of plants were made, two rows of kernels were taken from each ear. Three 100-gram sub-samples of the kernels were used for determining moisture content with an electric moisture testing device.

A severe wind storm on September 12 caused root lodging of some of the corn, and some of the stalks were broken. Rainfall and high humidity in August and September and during later months caused the grain to dry slowly. This delayed harvesting operations beyond the anticipated dates, and the late planted corn had not dried to the desired 15 per cent level even by the last harvest on December 1.

Three methods of harvesting were used which are designated "hand," "combination," and "machine." In the hand harvest, all ears were picked by hand from two classes of stalks. One class was stalks that were lodged because they were girdled, hereafter referred to as "girdled and lodged stalks." The second comprised all other stalks referred to as "not girdled and lodged." The combination harvest consisted of hand picking ears from "girdled and lodged stalks," then harvesting "not girdled and lodged" stalks by machine. In the machine harvest, all stalks from both classes were harvested in one operation by machine.

A record of the percentage of girdled and non-girdled stalks was made for each plot before harvesting for use in determining the effect of girdling on yield. A Massey Harris "82" grain combine with a corn header was used to do the harvesting. Three men were required in the operation. One man operated the machine, the second caught the grain from each sub-plot in a sack, and the third guided the combine operator to the plots to be harvested. Corn harvested by hand was run through the machine, after all plots had been machine harvested, in order to shell the grain from hand harvested ears.

The three harvest dates for each planting, as determined by previously described grain moisture tests, were as follows: For the April 25 planting -- September 7, October 13, and November 10. For the May 19 planting -- October 13, November 10, and December 1.

Treatment of the grain after harvest

Weights of grain harvested from each plot on each harvest date were converted to bushels per acre so that comparisons between the three harvesting methods could be made. Grain moisture tests were also obtained to determine differences between moisture content of grain from stalks that were girdled and on the ground and standing stalks. Plants that were lodged for reasons other than girdling were usually broken at a higher point, and ears were not in contact with the ground.

Survival of overwintering larvae

Data on survival of overwintering larvae were obtained from the plots after harvesting was completed. Stubs from each treatment plot of both plantings of corn were dug and dissected at eight-week intervals. Three dissections were made: the first on December 5, 1961, the second on January 30, 1962, and the third on March 27, 1962. On the last date not enough stalks were left in the plots of the early planted corn to take records, so data are available only on the first two dissection dates of that planting. Within each plot, consecutive stubs were dug and dissected until two live larvae were found. Other data recorded were the number of stubs dissected from each plot, the type of larvae, the number of stalks girdled, and the number of dead larvae within the stubs.

Totals were not made within each plot. The plots were used only to distribute the dissection throughout the field. An overall total of each item recorded was made of the entire field after each dissection.

RESULTS AND DISCUSSION

Larval development and activity

Early corn. Dissection of plants in the April 25 planting began on August 10 and terminated November 6, four days before the last harvest. By the beginning of dissection all second generation eggs had hatched, and essentially all of third generation eggs also, as indicated by the fact that there was no significant change in the percentage of plant infestation during August 10 to November 6 (table 3). An average of almost one-third of the plants dissected were infested during the period of study.

Data on population and change from summer form (spotted) to winter form (immaculate) larvae are given in table 1. On August 10 all borers found were spotted. The first immaculate borer was found on August 21. From that date, the percentage of winter larvae increased steadily until October 23 when 100 per cent of the larvae found were immaculate. At the two dissections made after October 23,all larvae found were immaculate.

On September 11 all larvae found were in the crown of the plants. There was no need to dissect the entire plant after all larvae had migrated to their winter quarters; therefore, beginning September 18, only the

Table 1. Population and larval change from summer to winter form of Z. grandiosella in early-planted corn, August 10 to November 6.

Date	Number Plants Examined	Number of Larvae: Summer Form	Number of Larvae: Winter Form	Number of Larvae: Total	Per Cent Winter Form	Number of Pupae
Aug. 10	133	59	0	59	0	3
21	67	18	1	19	5	2
24	69	21	1	22	5	1
28	68	29	4	33	12	1
31	68	11	5	16	31	1
Sept. 4	66	11	5	16	31	1
11	62	6	3	9	33	0
18	69	12	9	21	43	0
25	70	8	8	16	50	0
Oct. 2	70	4	13	17	76	0
9	65	2	17	19	89	0
16	70	2	21	23	91	0
23	68	0	19	19	100	0
30	73	0	21	21	100	0
Nov. 6	66	0	16	16	100	0
TOTALS	1084	183	143	326	-	9

crowns were dissected. Dissections were continued from this date until the last harvest mainly to observe the activity of the larvae in the plant crown, and to record the progress of girdling. The larva constructs a cell within the plant crown in which it spends the winter months. It bores to the extreme tip of the crown leaving only a thin portion of the plant between it and the soil beneath. The cell is lined with a silken web spun by the larva. The web lining of the cell provides protection from cold weather and prevents free water from coming in contact with the borer.

At some time during the preparation for winter, a majority of the overwintering southwestern corn borer larvae girdle the stalk of the plant they occupy. The larva chews a v-shaped groove into the plant rind from inside the stalk. This groove is usually cut around the entire circumference of the rind, but occasionally the process is only partially completed. At the level of girdling, all the plant fibers in the pith are cut by the borer chewing a cross section slice inside the stalk, leaving only a thin section of the rind on the outside to support the plant. Movement of the stalk by wind or other forces tends to cause the plant to break at the girdling point and fall to the ground. A majority of the girdled plants are girdled in the first or second internode above the ground, however, some are girdled in the third and fourth internodes (table 2). No plants in this study were found to be girdled above the fourth internode. The real purpose of this girdling is not known to this date. Some have suggested that wind moving the stalk may irritate the larvae causing them to girdle. It has been suggested that this may be necessary to regulate satisfactorily the humidity or oxygen supply during the winter. The author, however, has observed larvae girdling three-inch pieces of corn stalk placed in a glass vial for food where absolutely no wind was present. Early in the spring of 1961 when collecting overwintered borers to use for rearing moths for egg production, several borers were obtained from stalks which were not girdled. Girdling by this species is probably an inherent characteristic possessed by some but not all of the larval population, because not all of them girdle. Whatever may be the stimulus that causes this activity, it will be shown later that girdling increases winter survival.

Table 2. Location of Z. grandiosella larval girdles on early- and late-seeded corn plants.

Planting Date	Number of Plants Girdled at Various Locations					
	Ground Level	First Inter-node	Second Inter-node	Third Inter-node	Fourth Inter-node	Total
April 25	0	45	64	11	3	123
May 19	2	176	263	53	9	503
Total	2	221	327	64	12	626

Information on plant infestation and girdling activity is given in table 3. The per cent of plants infested was about the same throughout the study. The first girdling was

Table 3. Plant infestation and girdling by *Z. grandiosella* larvae in the early-planted corn, August 10 to November 6.

Date	Number of Plants Examined	Number of Plants Infested	Per cent Infested	Number of Plants Girdled	Per cent of Total Plants Girdled	Per cent Infested Plants Girdled
Aug. 10	133	45	32	0	0	0
21	67	18	27	0	0	0
24	69	21	30	2	3	14
28	68	27	39	7	10	26
31	68	26	39	7	10	27
Sept. 4	66	20	30	6	9	30
11	62	18	29	7	11	39
18	69	21	30	10	14	48
25	70	20	28	10	14	50
Oct. 2	70	20	28	11	15	55
9	65	19	29	10	15	53
16	70	23	33	12	17	52
23	68	19	28	12	18	63
30	73	21	29	15	21	71
Nov. 6	66	16	24	14	21	87
Total or Average	1084	334	30	-	-	-

recorded on August 24, and at the last dissection (November 6) about one-fifth of the dissected plants were girdled. The percentage of infested plants that were girdled rose to 87 on November 6.

To this date, information on the larval form of the southwestern corn borer that girdles the plant has not been available. Data of this type were taken in the periodic plant dissection studies during the summer and fall of 1961 by recording the larval form present in stalks that had been girdled. Information in table 4 shows that when girdling first appeared in the early-planted corn, many of the girdled plants contained only spotted larvae, ranging from 100 per cent on August 24 to zero on October 23 when all summer larvae had changed to the winter form. This is proof that the summer forms will girdle plants, but the data obtained in this study do not show that winter forms will girdle. The reason for the decrease in the percentage of girdled plants containing summer larvae is that many molted to the immaculate form before plants were dissected on later dates.

Late corn. The May 19 planting of corn had a much higher borer infestation than the April 25 planting. This was because the early corn missed a large part of the second generation larvae. The two plantings were located side by side in the field, and the moths emerging in July and early August preferred the younger, more tender plants of the late planting for oviposition sites. In addition, the per cent of establishment of young larvae was higher on late corn.

Table 4. Girdling by *Z. grandiosella* summer form (spotted) larvae in early-planted corn.

Date	Number of Girdled Plants Containing			Per Cent Containing Summer Form
	Summer Form	Winter Form	Total	
Aug. 10	0	0	0	-
21	0	0	0	-
24	2	0	2	100
28	4	3	7	57
31	4	3	7	57
Sept. 4	3	3	6	50
11	3	4	7	43
18	4	6	10	40
25	4	6	10	40
Oct. 2	2	9	11	18
9	2	8	10	20
16	2	10	12	16
23	0	15	15	00
30	0	15	15	00
Nov. 6	0	14	14	00
Total	30	93	123	0

Information on the population and larval change from summer (spotted) to winter (immaculate) form borers in the late-planted corn is given in table 5. One immaculate larva was found on the first dissection date. The percentage of immaculate borers increased throughout the

Table 5. Population and larval change from summer to winter form of *Z. grandiosella* in late-planted corn, August 16 to November 14.

Date	Number Plants Examined	Number of Larvae: Summer Form	Winter Form	Total	Per Cent Winter Form	Number of Pupae
Aug. 16	172	119	1	120	1	38
22	89	56	3	59	5	15
25	94	67	1	68	2	7
29	91	50	3	53	6	2
Sept. 1	92	67	8	75	11	0
5	81	35	10	45	22	0
8	80	44	12	56	21	0
12	71	38	10	48	21	0
15	82	47	19	66	28	0
19	91	50	21	71	30	2
22	82	43	14	57	25	1
26	94	32	31	63	49	0
29	86	18	25	43	58	0
Oct. 3	82	18	19	37	51	0
6	77	11	32	43	74	0
10	81	13	25	38	66	0
17	83	12	39	51	76	0
24	81	9	29	38	76	0
31	81	13	31	44	70	0
Nov. 7	81	8	34	42	81	0
14	79	4	40	44	91	0
Total	1850	754	407	1161	-	65

dissection period, but did not reach 100 per cent before the dissections were terminated. Beginning October 17 only the crowns were dissected. As in the early corn, all larvae had migrated to the crown by the first harvest even though some were still spotted. Almost all larvae change to the immaculate form after reaching the lower part of the plant, but on one occasion the author observed an immaculate borer in an ear shank. A cell had been prepared in the shank similar to those prepared in the crown by overwintering larvae.

When dissections began, pupae of the second generation were found. No other pupae were found until September 19 and 22 when three more were recorded. These could possibly have been from third generation larvae, but more likely they were from second generation that were late in pupating.

Information as to the girdling heighth in the late planted corn is combined with that of the early planting in table 2. Similar results were found as to where the larvae girdles the plant. Most girdling was done at the first and second internodes above ground; however, some girdled as high as the fourth. Two stalks were found girdled at ground level.

Plant infestation and girdling activity data in the late corn are given in table 6. The first girdling was recorded on August 25. Girdling of infested plants increased only 22 per cent from September 5 to November

Table 6. Plant infestation and girdling by *Z. grandiosella* larvae in late-planted corn, August 16 to November 14.

Date	Number of Plants Examined	Number of Plants Infested	Per cent Infested	Number of Plants Girdled	Per cent of Total Plants Girdled	Per cent Infested Plants Girdled
Aug. 16	172	84	48	0	0	0
22	89	47	52	0	0	0
25	94	55	59	4	4	8
29	91	50	55	14	15	28
Sept. 1	92	55	59	17	18	31
5	81	40	50	24	30	60
8	80	47	59	31	39	66
12	71	41	57	28	39	68
15	82	46	56	28	34	61
19	91	58	64	35	38	60
22	82	44	54	30	37	68
26	94	51	54	33	35	65
29	86	40	47	24	28	60
Oct. 3	82	33	40	22	27	66
6	77	42	56	27	35	64
10	81	38	47	27	33	71
17	83	45	54	30	36	66
24	81	38	47	27	33	71
31	81	44	54	33	41	75
Nov. 7	81	42	52	33	41	79
14	79	44	56	36	46	82
Total or Average	1850	984	53	-	-	-

14. Throughout this study an average of 53 per cent of the plants were infested. One hundred per cent girdling of infested plants was never reached--82 per cent being the highest on any date.

Data on girdling by summer form larvae in late corn shown in table 7 are similar to that recorded in the early corn (table 4). On August 25 when the first girdling was recorded, all four of the girdled stalks recorded contained only summer larvae, and as late as September 22, 50 per cent of the girdled plants had summer larvae. The percentage of summer larvae decreased after that date because many borers changed to the winter form before the crowns they occupied were dissected. Even though four summer form larvae were found on the last dissection date, none had girdled the plant they were in. No attempt was made to determine if winter larvae girdled.

Harvesting losses

When possible, harvesting was done in each planting of corn when the moisture content of the grain dropped to the desired levels. Immediately before harvesting, all stalks were counted in the rows to be harvested and recorded as either girdled and lodged or as all other stalks. This allowed a comparison between per cent girdling and yield losses.

Information on stalk girdling and moisture content of grain from the two planting dates is given in table 8. The percentage of stalks girdled in the early-planted

Table 7. Girdling by *Z. grandiosella* summer form (spotted) larvae in late-planted corn.

Date	Number of Girdled Plants Containing Summer Form	Winter Form	Total	Per cent Containing Summer Form
Aug. 16	0	0	0	--
22	0	0	0	--
25	4	0	4	100
29	12	2	14	86
Sept. 1	14	3	17	82
5	18	6	24	75
8	21	10	31	68
12	16	12	28	57
15	16	12	28	57
19	18	17	35	51
22	15	15	30	50
26	12	21	33	36
29	7	17	24	29
Oct. 3	6	16	22	27
6	5	22	27	19
10	5	22	27	19
17	3	27	30	10
24	3	24	27	11
31	5	28	33	15
Nov. 7	4	29	33	12
14	0	36	36	0
Total	184	319	503	-

corn during the periodic dissection studies varied widely from that recorded for harvested rows immediately before the first and second harvests (tables 3 and 8). This was probably due to sampling error. The percentage of girdling in the late-planted corn was approximately equal to that observed during dissections (table 6 and 8).

Table 8. Stalk girdling by *Z. grandiosella* larvae and grain moisture percentages in early- and late-planted corn.

Date of Harvest	Per cent of Stalks Girdled and Lodged	Per cent Moisture in Grain from: Girdled and Lodged	Not Girdled and Lodged
		Early Planted (April 25, 1961)	
Sept. 7	4	27	21
Oct. 13	9	19	16
Nov. 10	18	18	15
		Late Planted (May 19, 1961)	
Oct. 13	30	26	26
Nov. 10	36	21	19
Dec. 1	39	20	16

The first harvest in the early-planted corn was made September 7. On this date four per cent of the stalks were girdled and lodged, and the maximum girdling was 18 per cent on November 10 when the last harvest was taken. Moisture content was three to six per cent higher in grain from girdled and lodged stalks than from stalks without this damage. In the field planted May 19, girdling ranged from 30 per cent on October 13 to 39 per cent December 1. Grain from both classes of stalks had the same moisture content in the first harvest, but were two and four per cent higher in the girdled and lodged than in other plants in the later harvests. The generally higher moisture content of grain from girdled and lodged plants probably was due to contact of the ears with the ground.

Yield of grain obtained by the three methods of harvesting for the early corn is given in table 9. In the April planted corn, where girdling was low (table 8), yield from girdled and lodged plants was consistently low on all three harvest dates (table 9). Total yield by each method was about equal in the first harvest. On the second harvest (October 13) the combination harvest, where the machine was used to harvest stalks not girdled and lodged, gave five bushels per acre less than hand harvest; consequently, total yield was that much lower. Machine harvest of all stalks was 11 bushels less than with the combination procedure. On November 10, machine harvest of stalks not girdled and lodged was 11 bushels less than hand harvest, and machine harvest of all stalks gave 18 bushels less than hand harvest. These losses cannot be attributed to girdling alone, which involved only 18 per cent of stalks. Observations of the machine operation while harvesting showed that

Table 9. Yield of grain from early-planted corn.

Harvest Date	Stalk Class	Hand	Bu./Acre Comb.	Mach.
Sept. 7	Girdled and Lodged	2	2	-
	Not Girdled and Lodged	46	49	-
	Total	48	51	48
Oct. 13	Girdled and Lodged	3	3	-
	Not Girdled and Lodged	43	38	-
	Total	46	41	30
Nov. 10	Girdled and Lodged	3	2	-
	Not Girdled and Lodged	43	32	-
	Total	46	34	28

ears of many stalks blown over by the wind storm in September were not harvested.

In the late planting, yield from girdled and lodged stalks harvested by hand were about equal and all methods of harvesting gave about the same yield in the first harvest on October 13 (table 10). Hand and combination methods gave about equal yields in the second harvest (Nov. 10), but machine harvest was nine bushels per acre lower or about equal to the hand harvest from girdled and lodged stalks. The results obtained in the last harvest on

Table 10. Yield of grain from late-planted corn.

Harvest Date	Stalk Class	Bu./Acre Hand	Comb.	Mach.
Oct. 13	Girdled and Lodged	6	8	-
	Not Girdled and Lodged	19	19	-
	Total	25	27	26
Nov. 10	Girdled and Lodged	10	9	-
	Not Girdled and Lodged	18	18	-
	Total	28	27	19
Dec. 1	Girdled and Lodged	9	9	-
	Not Girdled and Lodged	17	15	-
	Total	26	24	19

December 1 were similar to those of the second harvest.

In the summer of 1960, a similar experiment was conducted but with only one planting date made May 12 and one harvest on November 4. A summary of the girdling and harvesting losses for the 1960 and 1961 tests is given in table 11. The early harvest in both plantings in 1961, when grain moisture was greater than 20 per cent, showed little or no loss with the machine. The per cent girdling and the per cent yield lost by machine are

Table 11. Summary of harvesting results for the 1960 and 1961 tests.

	Percentage		Per cent Less Than Hand Harvest	
Harvest Date	Moisture in Grain	Stalks Girdled & Lodged	Combination	Machine
		Planted May 12, 1960		
Nov. 4	15	30	12	35
		Planted April 25, 1961		
Sept. 7	22	4	+3	0
Oct. 13	15	9	3	10
Nov. 10	14	18	27	39
		Planted May 19, 1961		
Oct. 13	26	30	0	5
Nov. 10	18	36	10	38
Dec. 1	18	39	19	33

approximately equal in the following cases: in 1960, 30 and 35; second harvest in early planting, 9 and 10; second and third harvests in the late planting, 36 and 38, and 39 and 33; with mean values of 28 per cent girdling and 29 per cent loss.

The loss of 39 per cent with only 18 per cent girdled plants on November 10 in the earlier planting probably resulted from deterioration of the stalks after they were damaged by a wind storm. The reason for little or no loss by machine with the first harvest of both plantings was probably due to the incomplete severence of the stalk and stub by the borer at that early date. It was observed during harvesting that some of the girdled stalks were still attached to the stub firmly enough to be guided into the machine by the header without being broken off, thus, ears from many of the girdled and lodged stalks were harvested by the machine. The severence of the stalk from the stub, however, became more complete as the stalks deteriorated later in the season which accounts for the increased loss by machine harvest on the later dates.

Survival of overwintering larvae

Some information on survival of overwintering larvae was obtained from the test plots after harvest. Because of a limited number of plants available in the early corn, dissections were made on only two dates, December 5, and January 30. In the late corn an additional dissection was made on March 27. Consecutive plants in rows were dissected and classified as girdled or not girdled on the dates indicated in tables 12 and 13. The number of living and dead larvae were recorded for each class of plant. A girdled stub that contained no larva was considered as representing an overwintering larva that failed to survive and was recorded as "empty." The same assumption could not be made for tunneled non-girdled plants that contained no larvae, since it was not possible to determine if

Table 12. Survival of *Z. grandiosella* overwintering larvae in early-planted corn.

	December 5		January 30	
	Girdled	Not Girdled	Girdled	Not Girdled
No. Plants	100	432	203	815
No. Living Larvae	89	24	75	35
No. Dead Larvae	8	5	66	49
No. Empty Crowns	3	--	62	--
Per Cent Survival	89	--	32	--
Per cent of Living Larvae in:	72	28	68	32

overwintering larvae had been present. Because of this limitation, it was impossible to calculate the percentage of survival for overwintering larvae as was done for girdled plants.

Table 12 shows survival records in the early corn. Larval survival in girdled plants decreased from 89 to 32 per cent from December 5 to January 30. The per cent of all living larvae presented by plant types shows that the important reservoir was girdled plants. These data indicate that girdled plants constitute the important source of infestation for the following year's corn crop.

Larval survival records in the late corn are given in table 13. Survival in girdled plants decreased progressively from 32 to 6 per cent during December 5 to March 27. On each dissection date, the number of living overwintering

Table 13. Survival of *Z. grandiosella* overwintering larvae in late-planted corn.

	December 5		January 30		March 27	
	Girdled	Not Girdled	Girdled	Not Girdled	Girdled	Not Girdled
No. Plants	237	297	434	411	1416	1313
No. Living Larvae	75	41	92	22	84	30
No. Dead Larvae	6	3	48	34	150	116
No. Empty Crowns	156	-	294	-	1182	-
Per cent Survival	32	-	21	-	6	-
Per cent of Living Larvae in:	65	35	80	20	74	26

larvae in girdled plants exceeded those from non-girdled by ratios ranging from approximately 2:1 to 4:1, being 74:26 on March 27.

SUMMARY

The investigation included studies of the biology, seasonal development, and girdling activities of the southwestern corn borer, Zeadiatraea grandiosella (Dyar), in relation to grain yield losses in mechanical harvesting of corn.

The investigation extended through November in 1960 and from August 10, 1961, to March 27, 1962. A total of 8,592 plants were dissected and 4,310 borer specimens were processed.

Borer infestation levels and percentage of stalks girdled by borers were approximately twice as great in late corn as in early corn. This appeared to be due to moth preference of late corn for oviposition sites and to a higher establishment rate of young larvae on late corn.

Stalk girdling began in late August and continued to mid-November. Stalks were girdled from ground level up to the fourth internode above ground, with the first and second internodes containing the majority of girdles. Summer (spotted) larvae were proved to girdle stalks and the data suggest that all girdling was done by them. Transformation of summer to winter form (immaculate)

larvae began in mid-August and continued past mid-November. Winter survival of immaculate borers in girdled plants was approximately two to three times as high as that in plants not girdled.

The yield of early corn (planted April 25) was almost twice the yield of late corn (planted May 19) due to differential borer damage and weather conditions.

Stalk girdling markedly increased grain loss when corn was mechanically harvested. Since the percentage of stalks girdled and lodged progressively increased during the period of August to November, progressively higher grain losses occurred on each succeeding harvest date. Yield obtained from machine harvesting early corn on November 10 was 43 per cent less than on September 7. The December 1 harvest of late corn gave a yield 27 per cent less than that for the October 13 harvest.

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VITA

Donald L. Bailey

Candidate for the Degree of

Master of Science

Thesis: DEVELOPMENT AND GIRDLING ACTIVITY OF THE SOUTHWESTERN CORN BORER, *Zeadiatraea grandiosella* (Dyar), RELATED TO CORN HARVESTING LOSSES

Major: Entomology

Biographical and Other Items:

Born: Born near Sterling, Oklahoma, February 22, 1939, the son of W. L. and Erceline Bailey.

Undergraduate Study: Cameron State Agricultural College, Lawton, Oklahoma, 1957-59; Oklahoma State University, Stillwater, Oklahoma, 1959-61.

Graduate Study: Oklahoma State University, Stillwater, Oklahoma, 1961-62.

Experiences: Dairy farming, previous to 1957; Dairy worker (part time), Cameron State Agricultural College, 1947-59; Combine operator, Andrew Jensen, Manitou, Oklahoma (Oklahoma to Wyoming), Summer, 1959; Dairy worker (part time), Oklahoma State University, Dairy Department, 1959-61; Field Aide (part time), Oklahoma State University, Entomology Department, 1960-61; Field Aide, GS-3, Entomology Research Division, Agric. Res. Ser., U. S. D. A., Summer, 1961; Field Aide (part time), Oklahoma State University, Entomology Department, 1961-62; Field Aide, GS-3, Entomology Research Division, Agric. Res. Ser., U. S. D. A., Summer, 1962.

Member of the Entomological Society of America, Sanborn Entomology Club, and 2nd Lt., U. S. Army Reserve.

Date of Final Examination: August, 1962.