SORGHUM AS A HOST OF THE SOUTHWESTERN CORN BORER, *Zeadiatraea grandiosella* Dyar

By

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SORGHUM AS A HOST OF THE SOUTHWESTERN CORN

BORER, Zeadiatraea grandiosella Dyar

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PREFACE

The southwestern corn borer, primarily a pest of corn, has been reported infesting sorghum many times since it was first reported in the United States in 1930. Little definitive work has been done to determine the importance of this secondary host, since damage to sorghum by this borer in the past has been of little economic importance. Considering the indirect loss to corn producers due to the possible population increase from sorghum, additional broods by altering the period of larval development (due to different lengths of time required for completing a cycle on the two crops), or sorghum becoming severely infested in the absence of corn, it was deemed feasible to determine the potential of this borer to develop on sorghum. This was especially important if sorghum could serve as a source of overwintered brood, therefore increasing the population of the first generation on corn during the early summer when it is small and susceptible to heavy damage.

After a suggestion of this problem by Dr. R. R. Walton, Professor, Department of Entomology, and a discussion with him, Mr. K. D. Arbuthnot, Entomology Research Division, United States Department of Agriculture, and Mr. S. D. Hensley, a co-worker and graduate fellow at that time, but presently with the Entomology Research Division, United States Department of Agriculture, the writer decided to initiate a study of this borer on sorghum, with special emphasis on the possibility of its overwintering in this crop.

Data were taken at Stillwater, Oklahoma, during the period June, 1956 to June, 1957, from five sorghum varieties manually infested at four different ages throughout the summer.

I wish to express appreciation to several persons for valuable guidance and assistance during the study as well as in the manuscript preparation. Dr. R. R. Walton, who was instrumental in initiating the study, served as chairman of my graduate committee and gave valuable counsel on experimental procedures and manuscript preparation. Mr. K. D. Arbuthnot, who was also instrumental in initiating the study, supervised field research and assisted in obtaining some of the data. Mr. S. D. Hensley gave valuable suggestions on some phases of the study and assisted in taking some of the data. Mr. Frank F. Davies, Department of Agronomy, provided seed of the different sorghum varieties and gave valuable guidance on the agronomic aspects both in the field and in preparation of the manuscript. Drs. D. E. Howell, Head; D. E. Bryan, and F. A. Fenton, Department of Entomology, gave valuable suggestions on preparation of the manuscript. The Department of Entomology provided both field and laboratory facilities and equipment. Finally, I wish to express thanks to my wife, Sue Carol, and to Mrs. Charles Bacon, Jr. who typed and assisted in proofreading the manuscript.

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CHAPTER I

INTRODUCTION

During the period 1954 through 1956 extreme drought and high incidence of the southwestern corn borer, Zeadiatraea grandiosella Dyar severely limited the production of field corn in Oklahoma. As a result, acreages normally planted to corn have been increasingly planted to sorghum. Until now there has been little definitive work done on determining the possibility of the perpetuation of the southwestern corn borer on sorghum. It was the aim of this study to determine the biology of this insect upon several varieties of sorghum with emphasis on its potential to overwinter in this crop.

Apparently Z. grandiosella came from Mexico into the United States via Texas, Arizona, and New Mexico, prior to 1911 (Davis et al. 1933). Up to now it has been reported in 10 southwestern and central states. This area extends westward into Arizona, eastward into Arkansas, and northward as far as Nebraska (Anonymous 1955). Rapid spread of this pest from the area of entry into this country was restricted because of the difficulty in crossing the arid regions to the north and east in which little or no corn was grown (Todd and Thomas 1930). The pest was not found in Oklahoma until 1930, at which time it was reported in only two counties. By 1953 it had been reported in every county in the state (Hensley 1955).

At the present time there are several cultural recommendations for limiting damage by this insect, such as planting early on fertile soil, cutting stalks close to the ground level when plants are removed for forage or silage, uprooting stubble or plowing it under, and substituting sorghum for corn whenever practical. None of these measures used alone or in combination gives satisfactory control of this pest. Chemical control has not yet been proved economically feasible.

Although Z. grandiosella is primarily a pest of corn, it was found infesting sorghum as early as 1930 (Todd and Thomas 1930). Since that time it has been reported infesting sorghum in six states; although, infestations observed were light compared to that in corn (Todd and Thomas 1930, Davis et al. 1933, Wilbur et al. 1942, Walton 1945, Rolston 1955). Damage to grain sorghum is apparently of little economic concern, but Sorenson (1944), reported loss when borers feed in the heads of grain. Indirect loss to corn producers due to population increase from infested sorghum, additional broods by altering the period of larval development (due to different lengths of time for a cycle on the two crops), or sorghum becoming severely infested in the absence of corn could possibly be of importance (Rolston 1955). This is especially important if sorghum would provide a source of overwintered larvae capable of pupating, emerging as moths, and reproducing, thereby increasing the number of first generation borers in the early summer when corn is small and susceptible to heavy damage (Davis 1933).

To obtain desired knowledge of sorghum as a host source of overwintered larvae of the southwestern corn borer, a field study was made at Stillwater, Oklahoma, during 1956-57. Four different ages of five varieties of sorghum were manually infested to afford data on the potential of this borer to develop on this host. During the study, data were obtained on development, location, and survival of borers.

CHAPTER II

REVIEW OF LITERATURE

Synonymy

The southwestern corn borer, Zeadiatraea grandiosella Dyar, was first described from a single female moth collected at Guadalajara, Mexico (Dyar 1911). From 1911 to 1955 this species was identified with the generic name Diatraea. Box (1955), on the basis of the external genitalia, removed the species grandiosella from Diatraea and erected the genus Zeadiatraea to include it and the neotropical corn borer, formerly Distraea lineolata Walk., which does not occur in the United States (Box 1931).

Distribution in the United States

Hensley (1955) gave a comprehensive review of the distribution of Z. grandiosella on corn in the United States. He related the progressive spread by this borer from Mexico into nine southwestern and central states from 1930 through 1954. According to him, Arizona, New Mexico, Texas, Oklahoma, Kansas, Missouri, and Arkansas were reported infested in 1954. Colorado and Nebraska had infestations reported prior to 1945 but none since then. In Louisiana this borer was first found in 1955 (Oliver 1956).

Todd and Thomas (1930), in Texas, were the first to report Z. grandiosella infesting sorghum. Since then it has been reported attacking sorghum in the following states: Texas (Davis 1954), Arizona (Davis et al. 1933, Sorenson 1944, Vorhies and Wehrle 1946, Brantlinger

1953, Hopkins 1953, Werner 1956), New Mexico (Davis et al. 1933), Oklahoma (Walton 1945, Stiles and Hixson 1946, Arbuthnot 1953, Howell 1953), Kansas (Wilbur et al. 1942, Wilbur 1945, Wilbur et al. 1950), and Arkansas (Warren 1954, Rolston 1955).

Description

Dyar and Heinrich (1927) reported that larval characteristics could not be used to separate all species of Diatraea. Box (1931) using only adult characteristics in his key to the species of Diatraea, indicated that because of variation of individuals, positive identification sometimes requires close examination of the internal genitalia.

Heinrich, in 1933, gave a technical description of the larval, pupal, and adult stages of Z. grandiosella in which he stated that there is no consistent character, structural or otherwise, which has been found that will distinguish the larvae or pupae of the corn-feeding species of Diatraea (Davis et al. 1933). Peterson (1948) presented a key for the separation of the larvae of Z. grandiosella, D. saccharalis Fabr., and D. crambidoides Grote; however, he indicated it might not be valid for all variations of characters (Hensley 1955).

Davis et al. (1933) gave a general description of all stages of this insect as found in Arizona. The eggs were translucent white at deposition but within 24 hours they became cream-colored and three parallel transverse orange-red lines appeared dividing the egg into four more or less equal parts. About 24 hours before hatching, the eggs became yellow and the heads and thoracic plates of the enclosed larvae could be seen through the chorion as black spots.

The larvae presented two forms, a summer form with a milky-white coloration with brownish-black dots on the body, and a winter form which was a light butter-yellow color with no spots.

The pupae varied in coloration from the larval milky-white color to a dark brown within 24 hours after pupation began.

Seasonal history

Apparently, a variation of the seasonal history of Z. grandiosella is caused by the difference in environmental conditions over the area of its distribution within the United States. Davis et al. (1933) in Arizona, Thomas and McGregor (1937) in Texas, and Walton and Bieberdorf (1948) in Oklahoma, reported two complete and one partial third generation per year. Rolston (1955) in Arkansas, reported two complete and a partial third generation at Fayetteville; although, he found three complete generations and a trace of a fourth generation at Van Buren. Wilbur et al. (1950) reported two complete generations and a possible third in Kansas. All of these authors gave a detailed seasonal cycle of the pest as found in their respective areas.

The life cycle of Z. grandiosella on corn in the Payne County area of Oklahoma was given by Walton and Bieberdorf (1948, 1948a). Emergence of spring moths usually began during the latter half of May and continued until early June. The egg-laying period of the spring brood corresponded closely with the period of emergence. First generation larvae began to appear on plants about the middle of June, developed, pupated, and began emerging as adults about the middle of July. The majority of the second generation larvae did not usually pupate on reaching maturity but passed the winter in the larval stage; although, the larvae which did pupate usually emerged the latter part of August and early September. Third generation larvae, about two-thirds grown by October 2, were observed by these authors but the possibility of these larvae surviving and emerging as adults was undetermined.

Habits

Davis et al. (1933) gave a report of the habits of Z. grandiosella on corn. They pointed out that eggs hatched about five to six days after deposition, with 74 to 99 per cent of the entire egg output of each moth hatching. Hatching took place during the daylight hours, usually in the morning. The newly hatched larvae were very active and those of the earlier generations usually crawled to the bud of the plant to begin their feeding; although, early instar larvae of later generations during the year, which had to establish on older, tougher plants, established themselves between the leaf and the stalk to get succulent food. During the third or fourth instar the larvae left the bud and worked their way down the stalk, either by tunneling or by crawling on the outside. Larval maturity of the summer generation was usually attained by the time the larvae reached the lower level of the stalks. Prior to pupation the larvae cut exit holes to the exterior of the plants in preparation for moth emergence.

It was noted that the larvae, attempting to hibernate, tunneled to the extreme base of the stalk, cleared the tunnel to a point just above ground level, and sometimes chewed annular notches or girdles around the inside of the stalks a short distance above the ground. These girdles sometimes caused lodging of the plants. The creamy white immaculate form assumed by the larvae after reaching the base of the plant may be retained up to ten and one-half months. With rising spring temperatures the larvae became active, cleaned out their tunnels and extended them to the stalk surface, leaving only a thin outer shell of the stalk to serve as a protective cover.

The moths usually emerged during the early evening and spent the remainder of the night completing development. Mating, as observed only by Davis, usually occurred early the following night after emergence but occasionally on the night of emergence. Oviposition usually began on the second night after emergence or the night following mating, and continued for three or four nights, after which the females became very sluggish for a day or so and then died. Moths had an egg deposition range of 66 to 489 eggs each.

Food plants

Todd and Thomas (1930) first reported Z. grandiosella attacking forage crops other than corn. They reported milo, feterita, hegari, orange-top cane, and kafir were injured when adjacent to fields of heavily infested corn in northwest Texas. Davis et al. (1933) listed corn, grain sorghums, broomcorn, sugar cane, and Johnson grass as attacked by Z. grandiosella in New Mexico, but stated that only corn was severely damaged. Infestation of hosts other than corn ranged from 3 to 10 per cent of the plants infested.

Wilbur et al. (1942) stated that volunteer sorghum growing in heavily infested corn fields had as high as 54 per cent of the plants infested; although, no planted sorghum fields were more than four per cent infested. These authors reported infestation found in the Atlas, Kansas Orange, and Standard Yellow milo varieties. Later this borer was reported by Wilbur (1945) and Wilbur et al. (1950) as attacking all types of sorghum as well as field corn, sweet corn, and popcorn. Walton (1945) reported a light infestation of Z. grandiosella in grain sorghum, while Stiles and Hixson (1946) noted that it caused light damage to sorghum, broomcorn, Johnson grass, and Sudan grass in Oklahoma. Vorhies and

Wehrle (1946) reported infestations in these same crops in Arizona as well as in sugar cane.

Arbuthnot (1953) and Howell (1953) found Z. grandiosella on sorghum in Oklahoma, with the former reporting third brood eggs found on broomcorn, grain sorghum, and teosinte, in addition to corn and the latter noted that this borer hibernated commonly in sorghum during the winter of 1952-53. Brantlinger (1953) and Hopkins (1953) found Z. grandiosella on sorghum in 1953, in Arizona, with the former reporting as high as 30 per cent of the stalks infested in some grain sorghum fields.

Davis (1954) in Texas, and Warren (1954) in Arkansas reported 20 and almost 100 per cent, respectively, of the stalks infested in some varieties of sorghum. Rolston (1955) noted that in the absence of succulent corn, moths would oviposit freely on sorghum. He found eggs in fields of sorghum and on Sudan grass, millet, and Johnson grass growing in corn fields in Arkansas.

Damage to plants

Injury to plants is caused exclusively by the larvae. Davis et al. (1933) indicated that stalk injury due to larval tunneling is the most serious damage inflicted; although, they pointed out that severe injury might be caused by feeding on other parts of the plant.

Moths of Z. grandiosella apparently prefer to oviposit on corn; therefore, because of the low infestation level on sorghum in the past, injury to this crop has usually been of little economic importance (Davis et al. 1933, Wilbur et al. 1943, Walton 1945). Sorenson (1944) and Werner (1956), however, found moderate to severe damage on grain sorghum in Arizona, with the former reporting damage to the seed.

CHAPTER III

METHODS AND MATERIALS

Varieties of sorghum

Five sorghum varieties commonly grown in Oklahoma were used in this study. These were Redlan, Darset, Hegari, African Millet, and Sugar Drip.

Redlan is a combine-type of grain sorghum having juicy stalks growing to an average height of 42 inches and maturing in 118 to 120 days (Davies and Sieglinger 1952). Darset also is a combine-type grain sorghum averaging about 37 inches at maturity, some 115 days after planting (Davies and Sieglinger 1953). Hegari grown in Oklahoma by Finnell (1929) averaged 46 inches in height and matured in about 122 days. This variety is a grain-forage type of sorghum. This author also reported African Millet, a forage type variety, attained an average of 56 inches in height at maturity, some 118 days after planting. Sugar Drip is a medium-late variety of the forage type with an average syrup harvest date of 115 days (Sieglinger et al. 1949).

Field layout

A hand planting of four rows, approximately 150 feet in length, of each variety was made May 25, 1956. Varieties were planted in adjacent blocks with 42-inch spacing between rows. Plants were thinned to one plant every four to six inches when about four inches in height.

An attempt was made to simulate the cultural practices common under ordinary field conditions, but because of drought the entire planting was irrigated three times during the growing season by sprinkler-type irrigation equipment. Irrigation was used only after plants were observed to be wilting severely, and a serious threat of loss of plants was evident.

Egg production

Eggs were obtained from oviposition by moths in laboratory cages. From 30 to 50 pupae removed from corn plants, either naturally or manually infested with borers, were placed in petri dishes and covered with water-moistened cotton. Cages used to cover the petri dishes were made by removing the two ends of one-half gallon paper ice cream cartons. The cartons were lined with wax paper, commonly used for kitchen purposes, inserted in such a position as to fit snugly against the curvature of the carton. The inverted rim on the lower end of the carton, originally used to secure the bottom, secured the lower edge of the wax paper. The upper edge of the paper was fringed and turned to the exterior of the carton. Thin nylon mesh was placed over the upper end and secured by the rim of the lid.

Moth emergence, copulation, and egg deposition occurring within each cage were somewhat irregular over a period of about 10 to 12 days. Daily observations of each cage were made and wax papers having eggs deposited on them were removed daily from the cages and dated. These papers, with few exceptions, were removed sometime during the morning hours, as it was observed that egg deposition occurred during the hours of darkness.

During the first two and the last infestation of this study, egg deposition cages were kept in the laboratory at room temperatures generally within a range of 70 to 100 degrees Fahrenheit, but, as the summer temperatures became higher the cages were moved into the basement where temperatures ranged from 70 to 80 degrees Fahrenheit. Humidity was increased in the cages by moistening the cotton placed over the pupae, and by adding water to the sand on which the cages were placed. Controlled temperature and humidity conditions within the deposition cages were not sought in this study and both were varied in order to obtain the highest egg production possible.

Procedure used to manually infest plants

After the wax papers were removed and dated, the eggs deposited on them were observed daily for embryonic development. Shortly after the appearance of evidence of egg fertility, the papers were cut into fragments with a razor blade, each fragment, as nearly as could be ascertained without magnification, containing five eggs. Deposition on the wax paper in the cages was variable, ranging from a single egg to clusters containing as many as 30 eggs. Fragments of paper having less than five eggs were sometimes combined and in many cases when a sufficient number of eggs could not be obtained otherwise, the large masses of eggs were sliced apart to afford the five eggs needed on each fragment. A straight pin was thrust through each of the fragments of paper with the eggs toward the pin head. These pins were aligned in rows on small squares of corrugated cardboard, 120 pins to each board. About 24 hours before hatching, the eggs were transferred from the laboratory to the plants in the field. The pins were pushed into the leaf sheath of the plant, about eight inches above ground level, until the wax paper touched the plant. Eggs were placed about half-way from the ground to the top of the plants in the fourth infestation since the lower portion of the plants had dried after reaching maturity.

Table 1 gives the dates of egg deposition and when the eggs were placed on the plants of the four different infestations throughout the summer. Due to the difficulty of obtaining eggs at such late dates during the season only 80 plants of each variety, in the fourth infestation, were infested. In each infestation care was taken to assure that no plant suckers were used. With exception of the fourth infestation, all plants of a variety were infested before beginning another variety. In the fourth infestation the same number of plants of all varieties was infested on each day.

Table 1. Date of deposition and placement of eggs on the plants for the four different infestations during the summer.

Infestation Number	Date: Eggs Deposited	Date: Placed on Plants
1	July 2-7	July 6-11
2	July 19-28	July 22-31
3	August 6-10	August 10-13
4	August 30-September 8	September 2-12

At the time of infesting, all plants were numbered with a wax pencil about six inches above the ground level on the stalks. These numbers were legible for a period of three months or longer if placed on the stalk and not on the leaf sheaths.

Egg hatch counts and plant measurements

The number of eggs hatched on each plant was recorded 48 to 72 hours after placing the eggs on the plants. When the egg shells were not found on the fragments of wax paper pinned on the plants, it was assumed that the eggs had hatched and the remains of the shells had been destroyed by wind or moisture.

Every fifth plant in the row of each infestation was measured for height at the time of recording the egg hatch. Plants were measured by placing a measuring stick on the ground at the base of the plant and holding it as perpendicular to the ground surface as could be ascertained. The upper leaves of the plant were grasped loosely in the hand and extended to their highest point on the measuring stick. All measurements were recorded on the basis of individual standing plants.

Allocation of infested plants to different phases of the study

Because of lack of knowledge of the establishment, development, and survival of *Z. grandiosella* on sorghum, allocation of infested plants for a particular phase of the study was based on the activity and reaction of the borers observed on or in the plants. As previously stated, the primary purpose of this study was to obtain information on the overwintering potential of this borer on sorghum as a host plant. Careful consideration was given before removing from the field any number of plants which could cause a serious depletion of material for the overwintering phase of the study.

Observations of the plants infested during the first infestation were made bi-weekly, beginning with the hatching of eggs. On August 11, a number of moth exit holes were observed in the Redlan, Darset, African Millet, and Sugar Drip varieties. Assuming the borers were pupating, 30 plants of each variety were removed and dissected to obtain information concerning development and survival.

Dissection was accomplished by first cutting the plant into two pieces at the second internode above ground level and carefully splitting the below ground portion of the plant with a pocket knife. Each internode from the base of the plant through the peduncle was then carefully dissected. Data on each plant were recorded separately in a field notebook. These data consisted of the stage found, instar of borer (if applicable), location within the plant, and fate of the stage observed.

The remaining 90 plants of each variety in the first infestation were observed weekly for indication of borers attempting to overwinter within the plants. Girdling of the plants, causing them to lodge, or plugging of exterior holes near the base of the plant were used as indicators of hibernation. During the week of October 27, when girdling had apparently ceased, the remaining 90 plants of each variety in the first infestation, exclusive of girdled plants were removed and dissected. The lodged portions of the girdled plants were also dissected and it was assumed that each girdled plant contained a live overwintering larva. Where moth exit holes were found in the sorghum stalk, but no pupal cases were present in the tunnels within the plants, it was assumed the pupal cases had been dragged to the exterior of the plant by the emerging moths.

Data recorded for each plant were the pupal cases, immaculate larvae, assumed overwintering larvae, and location of the different forms within the plant.

Thirty plants from each variety (plants 70 through 99) in the second infestation were tagged for obtaining information concerning the life cycle, development, migration on or in the plant, and the survival of the borer in sorghum. The plants were tagged with a small weatherproofed tag about 10 inches above the ground level by loosely looping the stalk with a wire. An assigned number to each variety and the plant number within the row were placed on the tags with India ink for reference during later dissections.

All 30 plants of each of the varieties were infested with eggs deposited on the same date. At this time additional plants of all varieties, other than those used in this study, were also infested with eggs deposited by moths on the same date. Larvae observed from dissection of these plants served as an indicator for the time required between dissections in the study to obtain progressive instars. Based on the observations from the indicator plants, five plants each date were dissected beginning within 48 hours after eggs hatched. Dissection of these plants was similiar to previous dissections except that all plants in this phase of the study were scrutinized upward from about one-half inch above ground level, including the head of the plant. Data consisted of date of dissections, plant height and stage of development, instars and number of borers, and location within or on the plant.

After five dissections were made, and some 25 to 33 days after egg hatch on the different varieties of sorghum, the number of plants of each dissection was reduced to two. No indication of pupation of borers was observed during dissections in any variety; therefore, the remainder of the 30 plants of each variety remained in the field. These plants were closely observed during the remainder of the summer and fall for indication of pupation or of hibernating larvae. During the period of pupation of borers the following spring, these plants were dissected to determine, if possible, the fate of the borers which hatched from eggs placed on the plants. The remainder of plants in all varieties of this infestation, along with all the plants of the third infestation were left in the field to supply material for the study on overwintering.

On November 16, following the second temperature decline to below freezing, 40 plants of the fourth infestation, with exception to the girdled plants, were dissected to determine the effect of freezing temperatures on the borers above ground level within the plants. On November 21, following the third temperature decline to below freezing, the remaining 40 plants of this infestation were dissected for the same purpose. The larval instars, location within the plants, and the fate of the borers were recorded during both dissections.

Determination of girdled plants

On August 22, girdling of plants was observed in the first infestation of African Millet. Thereafter weekly observation of all infestations were made to determine the extent of girdling. Many of the girdled plants were held upright by extensive foliage of the plants growing close together. These plants, although girdled completely around the interior of the stalk, did not lodge and were not apparent as girdles; therefore, girdled plants were determined by tapping each plant with the hand while walking between the rows. This light blow administered with the back of the hand was sufficient to cause the plant to lodge.

All girdled plants were numbered (staked) and the number, date of girdling, plant number within the row, and the number of the infestation were recorded.

Overwintering observations

Plants of the second and third infestation were used for overwintering observations. On October 27, each variety of these two infestations were divided into 12 samples of 10 plants each and staked accordingly. One ten-plant sample from each row of sorghum or 20 plants from each variety were to be removed from the field and dissected for determining survival of the borers at intervals of four weeks beginning November 3, 1956, and terminating April 20, 1957.

The location of the ten-plant samples within each row for each observation date was predetermined by a randomized method at the time of staking the samples. Because of the previous removal of plants numbered 70 through 99 from the second infestation for the life cycle phase of the study, only 10 plants within a variety were dissected and observed on certain observation dates. In each sample, plants were dug from the ground with a shovel, dissected into two pieces at the second internode above the ground level, and the crown carefully split with a knife and observed for larvae. The remainder of the plant was carefully dissected upward from the base through the peduncle. After the fourth observation on January 26, 1957, dissection of the plant portion above the ground level was discontinued. Previous observations indicated larvae located in the plant above the ground could not survive. All larvae were removed from the plants during the dissections, placed in paper cartons, and transferred to the laboratory for later observations. At the time some of the periodic observations were made, the temperatures in the field were below freezing; therefore, upon removal of the inactive larvae from each variety of sorghum they were immediately moved into room temperature within the laboratory. These larvae were observed for activity several times during the following 24 hours. At room temperature the live larvae usually showed movement within 20 to 30 minutes. Dead larvae could usually be ascertained in the field due to their darker coloration and lack of rigidity of the body.

Only the underground portion of the girdled plants was dissected and observed, because the lodged portion of the plants and other plant debris had obviously been shifted about in the field by wind and water making it questionable to use information derived from them. Data were recorded in the field at the time of each observation. When the fate of a borer was not definitely determined in the field, delayed observations in the laboratory were used to supplement field data.

Emergence of overwintering brood

Girdled plants of all four infestations were used to determine survival of the overwintering brood through moth emergence. On May 17, 1957, all non-girdled plants in the field were removed and the underground portions examined for overwintering borers. Data were recorded as to the forms observed, the variety, and the infestation number. All girdled plants not found during the fall of 1956 were staked with unmarked stakes.

Because of an unusual amount of rainfall during the period of overwintering brood pupation, much of the debris and top soil of the field began to wash. This debris and top soil was found to be plugging many of the exit holes in the stubble cut by the overwintering larvae for the moths to escape. Plugging of the exit holes occurred after the borers had pupated; therefore, to allow the moths to escape, the stubble was cut off about one-half inch below the moth exit holes.

On May 22, cages were placed over individual sorghum stubs to prevent escape of the moths upon emergence. These cages were made of sections of glass tubing about six inches in length and one and one-half inches in diameter and covered at the upper end with nylon mesh held in place by a rubber band. The end of the tubing on which the nylon mesh was to be placed was first dipped into melted beeswax to prevent the sharp edges of the glass cutting the nylon. These cages were placed firmly in the soil around the base of the stubble to prevent overturning by rain or wind. Because of heavy rains occurring during the time the cages were in the field, covers were placed over the cages each time rainfall was expected. These covers were made by removing one end of a metal 12-ounce beverage can and were placed over and around the tube cages.

Cages were observed for moths twice daily, during the early morning and evening hours. Moths which emerged from the underground portion of the plants were recorded by variety of sorghum and the number of the infestation. If the plants were staked for the time of girdling the previous fall, the plant number was also recorded.

Fifty corn plants determined as girdled were treated in the same manner as sorghum to afford comparative data between the two crops. The corn plants were located in a similiar soil type to that of sorghum with the two fields being separated only by a building.

Overwintering brood fertility

During the twice daily observations, cages found containing moths were pressed into the ground to a sufficient depth to plug the lower end of the cage with soil and then taken from the field. Records were kept in a field notebook and cages were marked indicating the variety and the number of the infestation from which the moth emerged.

Sex of the moths was determined in the laboratory, and each female was placed with a male in a small deposition cage. These egg deposition cages were made of six-inch sections of one and one-half inch glass tubing, lined with wax paper, and enclosed at both ends with nylon mesh.

Daily records were kept of females depositing eggs. Wax papers with eggs deposited on them were removed from the cages each morning, dated, and identified by marking with the cage number. The following day eggs were counted by using a dissecting scope (30x) and data were recorded on fertility, and numbers produced by each female. Each morning dead moths were removed from the cages and were recorded appropriately.

Data concerning the hatching of fertile eggs were not recorded because fluctuation of temperature and humidity within the room may have affected their development; although, it was observed that most of the fertile eggs hatched.

CHAPTER IV

RESULTS

Development and survival of summer form borers

Sorghum infested during the vegetative stage. At the time the eggs hatched on the plants all five varieties were in the vegetative whorl stage with Redlan having an average height of 40 inches; Darset, 36 inches; Hegari, 43 inches; African Millet, 56 inches; and Sugar Drip, 53 inches. The number and per cent of the different forms of *Z. grandiosella* found in the different varieties of sorghum 38 to 40 days after egg deposition are given in Table 2. At the time data were taken on these plants, Redlan and Darset had grain-filled heads, but Hegari, African Millet, and Sugar Drip had heads only forming in the boots.

As exemplified by the different forms on the varieties Darset, Hegari, and Sugar Drip, there was considerable variation in development of borers on the individual plants of the same variety, and sometimes on different portions of the same plant. When the plants were in the vegetative stage, the variety African Millet apparently provided the environmental conditions suitable for more rapid development of this borer, followed by Redlan, Sugar Drip, Hegari, and Darset, respectively (Table 2). Data recorded on the maturity of individual plants indicated borers which established on younger plants generally developed more rapidly than those establishing on more mature plants.

Table 2. Number and per cent of the different forms of Z. grandiosella Dyar found in vegetative stage sorghum 38-40 days after egg deposition.

Variety	Larval Instars IV No.	Larval Instars IV %	Larval Instars V No.	Larval Instars V %	Larval Instars VI No.	Larval Instars VI %	Pupae No.	Pupae %	Pupal Cases No.	Pupal Cases %
Redlan			3	14.2	11	52.5	7	33.3		
Darset	2	9.0	7	31.8	8	36.4	1	4.5	4	18.2
Hegari	2	13.4	3	20.0	9	60.0	1	6.7		
African Millet					9	36.0	15	60.0	1	4.0
Sugar Drip	2	5.6	7	19.4	17	47.2	10	27.8		
Total	6	5.0	20	16.8	54	45.4	34	28.6	5	4.2

The data in Table 3 show the per cent survival of the borers only to a period of time 38 to 40 days after egg deposition. Of approximately 750 eggs placed on the 150 plants, 645 hatched, accounting for an average of 4.26 borers per plant having an opportunity to establish and survive. A total of 119 forms (fourth instar through pupal cases) or approximately 18 per cent survived 38 to 40 days. This showed an average survival of 0.79 borer per plant. Survival of borers was highest in the variety Sugar Drip on which 26.5 per cent of the hatched borers survived. From 17.1 to 18.7 per cent survival occurred on Redlan, Darset, and African Millet, while Hegari showed only 11.5 per cent (Table 3).

Table 3. Survival of Z. grandiosella Dyar 38 to 40 days after egg deposition on sorghum infested while in the vegetative stage.

Variety[1]	Total Eggs Hatched on Plants	Total No. Forms[2]	Per Cent Survival
Redlan	123	21	17.1
Darset	122	22	18.0
Hegari	130	15	11.5
African Millet	134	25	18.7
Sugar Drip	136	36	26.5
Total or Average	645	119	18.5

[1]Thirty plants per variety.
[2]Fourth instar larvae through pupal cases.

Establishment of early instar borers on or in the individual plants was not uniform; no borers were found in 69 of the 150 plants dissected. Close examination disclosed no apparent damage to many plants in all varieties, indicating mortality or some other unknown fate of the borers occurred before damage was done. Because of proximity of plants, a considerable amount of migration from one plant to another occurred within the row. Indication of this was noted through recovery of borers from suckers of infested plants which themselves did not receive eggs. It is possible that borers hatching on plants which later showed no signs of borer damage, migrated to nearby plants within the same row.

During the week of October 27, some data were obtained on survival to moth emergence or immaculate larvae. These data included the number of pupal cases and the number of immaculate larvae sometimes indicated by girdling of plants. Each girdled plant was assumed to represent one immaculate larva. Approximately 86 per cent of 2,250 eggs placed on the 450 plants of all the varieties combined hatched. An average of 4.24 borers had an opportunity to establish on each plant. Of the 450 plants dissected, 38 per cent contained no borers, with the majority having no tunneling damage apparent. A total of 14.4 per cent of the total forms recorded for this dissection was found in suckers of the infested plants; these suckers received no eggs. Again the absence of borers from some plants and their presence on suckers may be accounted for in part by migration. The survival data are given for each variety in Table 4. Percentage of survival based on data from the 90 plants of each variety differ considerably from the data taken from the 30 plant samples previously reported in Table 3. Apparently this variation in results is partially due to the smaller number of plants sampled in the earlier dissection, and it is believed survival on vegetative stage sorghum as shown in Table 4 is more accurate for each of the varieties. Sugar Drip appeared to provide environmental conditions more suitable for summer survival, with approximately 25 per cent total survival of borers, compares favorably to that reported in Table 3. Hegari, African Millt, and Redlan all provided conditions suitable for more than 20 per cent survival.

Table 4. Survival of borers to moth emergence or immaculate larvae as found on sorghum infested while in the vegetative stage.

	Variety of Sorghum[1]					
	Redlan	Darset	Hegari	African Millet	Sugar Drip	On All Varieties
Number of eggs hatched on plants	370	396	379	419	345	1909
Total number of forms	77	69	94	95	88	423
Number of pupal cases[2]	60	45	66	66	70	307
Per cent emergence	77.9	65.2	70.2	69.5	79.5	72.6
Number of immaculate larvae[3]	17	24	28	29	18	116
Per cent immaculate	22.1	34.8	29.8	30.5	20.5	27.4
Per cent total survival based on hatch	20.8	17.4	24.8	22.7	25.5	22.2

[1]Based on 90 plants per variety.
[2]When gates were observed but no pupal cases were present in tunnels it was assumed the case was dragged from the plant by the emerging moth.
[3]Girdled stalks were assumed to contain one live overwintering larva.

<u>Sorghum infested during boot to grain-filled stage</u>. Data relating to larval development and survival, recorded from the dissection of five plants at different intervals after egg deposition, of the varieties Redlan and Hegari are shown in Table 5. Data taken from the other three varieties were not tabulated because so few borers were recovered. At

the time of infesting the plants from which these data were taken, Redlan had approximately 30 per cent of the plants with heads extruding from the boot; Darset had 100 per cent grain-filled heads; and Hegari, African Millet, and Sugar Drip had no heads showing.

Apparently most of the larval mortality occurred when they were attempting to establish on the plants. Dissection of five plants each of the varieties Redlan and Hegari, one day after eggs hatched on the plants, showed approximately 30 per cent recovery of borers. Later dissections of the same number of plants indicated a much slower decline of survival in subsequent instars.

Data indicated considerable variation in the amount of time required for individual larvae to develop through all the instars. This variation was found to occur not only between larvae located on different varieties but also between different plants within the same variety and occasionally between those located in different portions of the same plant. On Redlan the first instar larvae were found six days after egg deposition; second instar, 6 to 10 days; third instar, 10 to 19 days; fourth instar, 14 to 25 days; fifth instar, 14 to 25 days; and sixth instar, 25 to 36 days. First instar larvae were found on Hegari six days after egg deposition; second instar, nine days; third instar, 14 to 24 days; and fourth instar at 34 days. No larvae beyond the fourth instar were recovered from Hegari.

Although establishment and/or survival were very low in the varieties Darset, African Millet, and Sugar Drip, the few larvae which did survive were similiar in rate of development to those found on Redlan. Third instar borers were found on Darset and African Millet at 20 days and fourth instar on Sugar Drip at 19 days.

Table 5. Stage of development and survival of larvae on the sorghum varieties Redlan and Hegari found through dissection of five plant samples at different time intervals after egg deposition.

Days Interval	Larval Instar	No. of Larvae	Total Larvae	No. of Eggs Hatched on Plants	Per Cent Survival[1]
			Redlan		
6	I	3			
	II	4	7	23	30.43
10	II	1			
	III	4	5	22	22.73
14	IV	9			
	V	1	10	27	37.04
19	III	1			
	IV	1			
	V	1	3	25	12.00
25	IV	2			
	V	2			
	VI	1	5	26	19.23
36[2]	VI	2	2	10	20.00
			Hegari		
6	I	7	7	23	30.43
9	II	4	4	25	16.00
14	III	1	1	26	3.84
19	III	2	2	33	6.06
24	III	5	5	27	18.52
34[2]	IV	1	1	11	9.09

[1]Based on number of eggs hatched on the plants and total number of larvae observed during each dissection.

[2]Only two plants were dissected during the last dissection of each variety.

Sorghum infested during the mature stage. Very low survival was found for borers hatched on plants having grain at or near maturity and dead leaves on the lower one-third of the plants. Of approximately 2,000 eggs placed on 400 plants (80 plants per variety), 1,923 hatched, affording an opportunity for establishment of an average of 4.8 borers per plant. External observations made without manipulating the plants during the period between egg hatch and dissection of the plants gave no evidence of establishment of borers. From 73 to 78 days after egg hatch, plant dissections on each of two dates, November 16 and 21, showed some establishment occurred but total survival to these dates was low. Based on the number of eggs hatched the average per cent survival was 2.2, ranging from 0.3 to 4.4 for the different varieties (Table 6).

It is believed that plant conditions during development of the borers greatly affected survival. Darset and Redlan had little green tissue within the stalks, although, Darset had many side branches of secondary growth developing from the lower nodes of the plants. African Millet and Sugar Drip, and to a lesser extent Hegari, had more green plant tissue in the stalk than the other two varieties. Redlan with the least green tissue showed the lowest survival of borers. Darset, with low green tissue content in the stalk, showed a higher degree of survival but the majority of the borers recovered were in the side branches described above.

Temperature declines to below freezing, which occurred three times before dissections were completed, were believed to be the major cause of mortality of recovered larvae. Of all larvae recovered, 80.5 per cent were living (Table 6). None of the recovered larvae which were dead showed marked discoloration or deterioration, thereby indicating recent death.

Table 6. Fate of larvae on sorghum, infested at or near grain maturity, as indicated by dissections after declines of temperature to below freezing.

	Variety of Sorghum[1]					
	Redlan	Darset	Hegari	African Millet	Sugar Drip	Average
Spotted forms alive		4	5	5	15	5.9
Spotted forms dead	2	4	2	0	0	1.6
Immaculate larvae in non-girdled plants		3	1	0	0	0.8
Immaculate larvae in girdled plants[2]	1	3	1	3	1	1.8
Per cent of recovered larvae alive	33.3	71.4	77.7	100.0	100.0	80.5
Total number of eggs hatched	381	399	431	349	363	384.6
Per cent survival based on hatch	0.3	2.5	1.6	2.3	4.4	2.2

[1]Forty plants of each variety dissected on each of two dates, November 16 and 21.
[2]Each girdled plant assumed to represent one immaculate larva.

The data obtained from dissections made on the two dates do not depict progressive development of larvae. However, larvae were found to be either of the sixth instar summer form or to be immaculate except for two fifth instar larvae, one each in the varieties Darset and Hegari.

<u>Location of summer form borers on or in the plants</u>

<u>Sorghum infested during the vegetative stage</u>. Moth exit holes, indicating the beginning of pupation, were first found in the variety African Millet August 11, 38 days after deposition of eggs. Immediately

after finding these exit holes, 30 plants from each variety were removed and dissected. When data were taken the grain type varieties had grain-filled heads but the grain-forage and the forage types had heads forming only in the boots.

A pronounced difference in the location of sixth instar and subsequent stages within the plants was found to occur between the grain and forage type sorghum (Table 7). The grain type sorghum had 20.6 per cent of all the late instar larvae, pupae, and pupal cases located in the peduncle or whorl of the plants. No borers were recovered from this part of the plants on the forage type.

By consolidating the per cent of all the stages found below ground level and in the first seven internodes above ground level as given in Table 7, it was found that 63.1 and 84.0 per cent were located in these parts of the plants for the grain and forage types, respectively. These plant parts roughly constitute the lower half of the plants.

The most pronounced difference in location of borers in the plants was found to occur between Darset and the remainder of the varieties. As shown in Table 8, this variety had 27.3 per cent of all stages located in the peduncle. Consolidation of the data given in Table 8 showed that 54.5 per cent of all stages recovered from this variety were located in the upper half of the plants. It is believed that toughness and unpalatability of the plant tissue, because of the extremely short internodes, may have contributed to the greater number of borers found in the upper half of the plants in Darset. The greater percentage of all stages in the remainder of the varieties was found below ground or in the first seven internodes above ground level.

Table 7. Per cent of the different stages of borers located in various plant parts as found by dissection 38 to 40 days after egg deposition.

Stage	Below Ground	Internode Number Above Ground 1	2	3	4	5	6	7	8	9	Peduncle
						Grain Type Sorghum[1]					
Instar IV							50.0				50.0
Instar V	20.0				10.0	10.0	20.0	20.0		20.0	
Instar VI	5.3			15.8	15.8	10.5	21.0	5.3	15.8		10.5
Pupae				25.0		12.5		12.5		12.5	37.5
Pupal cases										25.0	75.0
Per cent of all stages	7.0			11.6	9.3	9.3	16.6	9.3	7.0	9.3	20.6
						Forage Type Sorghum[1]					
Instar IV									50.0	50.0	
Instar V				16.6				50.0	16.6	16.6	
Instar VI	25.9	3.7		7.4	11.1	14.8	11.1	11.1	11.1	3.7	
Pupae	8.0		12.0	4.0	8.0	24.0	24.0	12.0		8.0	
Pupal cases							100.0				
Per cent of all stages	14.8	1.6	4.8	8.0	8.0	16.0	16.0	12.8	8.0	8.0	0.0

[1]Sixty plants of each sorghum type dissected.

Table 8. Numbers of the different instars and stages of borers in the various plant parts 38-40 days after egg deposition as found on plants infested while in the boot stage.

Instar	Below	Internode No. Above Ground									
or Stage	Ground	1	2	3	4	5	6	7	8	9	Peduncle
						Redlan					
V	1				1			1			
VI	1			2	3	2	2				1
Pupae				2		1		1		1	2
Total	2	0	0	4	4	3	2	2	0	1	3
Per cent	9.5	0	0	19.0	19.0	14.2	9.5	9.5	0	4.8	14.2
						Darset					
IV							1				1
V	1					1	2	1		2	
VI				1			2	1	3		1
Pupae											1
Pupal cases										1	3
Total	1	0	0	1	0	1	5	2	3	3	6
Per cent	4.5	0	0	4.6	0	4.6	22.7	9.1	13.6	13.6	27.3
						Hegari					
IV							1				1[1]
V					1		1	1			
VI	7						1			1	
Pupae	1										
Total	8	0	0	0	1	0	3	1	0	1	1
Per cent	53.4	0	0	0	6.6	0	20.0	6.6	0	6.6	6.6
						African Millet					
VI	3			1		3		1	1		
Pupae	1		2		1	3	5	3			
Pupal cases							1				
Total	4	0	2	1	1	6	6	4	1	0	0
Per cent	16.0	0	8.0	4.0	4.0	27.2	27.2	16.0	4.0	0	0
						Sugar Drip					
IV									1	1	
V				1				3	1	1	
VI	4	1		1	3	1	3	2	2	1	
Pupae	1		1	1	1	3	1			2	
Total	5	1	1	3	4	4	4	5	4	5	0
Per cent	13.9	2.8	2.8	8.3	11.1	11.1	11.1	13.9	11.1	13.9	0

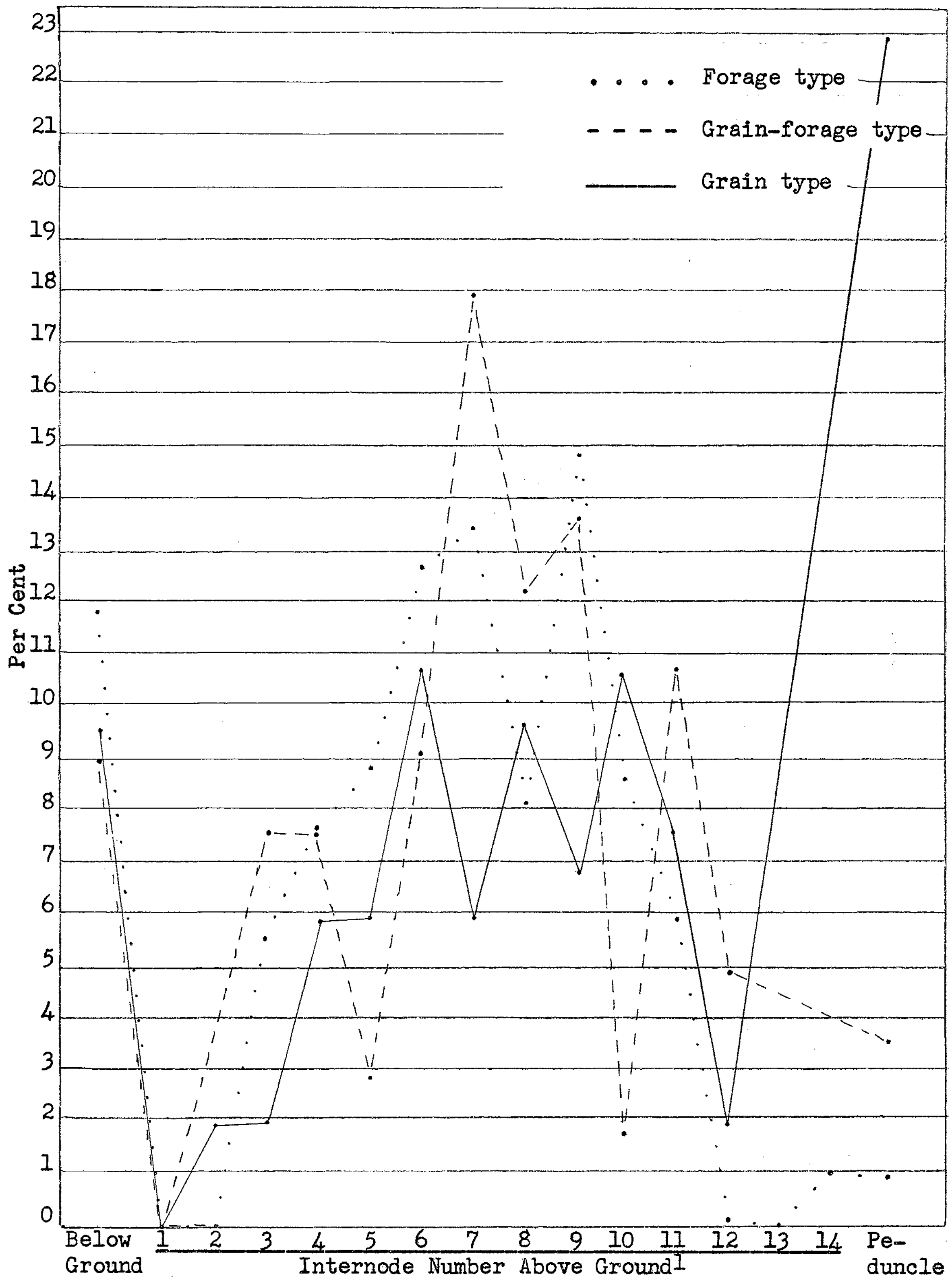
[1]Found in the whorl of a vegetative stage plant.

Further evidence of difference in the location of borers within the various types of sorghum was found by dissection of 90 plants of each of the five varieties. The borers from these plants developed on or in the plants at the same time as those discussed above, but to allow for girdling of plants which was presumed could occur, the plants were not dissected until the week of October 27. Three-hundred and seven pupal cases and 125 immaculate larvae were recovered from these plants.

Figure 1 shows the variation in location of pupal cases found within the different types of sorghum. The grain type had 22.9 per cent of all the pupal cases located in the peduncle, while only 3.1 and 1.5 per cent were found in the grain-forage and forage types, respectively.

The grain-forage and forage type sorghum showed greater concentration of pupal cases in the internodes comprising the middle third of the plants. The grain type sorghum had the same trend but to a lesser degree, with the individual internodes near the middle of the plant approaching less than half the number of pupal cases found in the peduncle.

Data in Table 9 show that 40.7 per cent of the pupal cases found in the grain type were located in or below the seventh internode. The grain-forage and forage types had 54.5 and 58.2 per cent, respectively, located in this portion of the plants. These percentages are consistent as far as types of sorghum are concerned but are considerably less than those reported previously for this portion of the plant. When the immaculate larvae are included the per cent of total forms found in or below the seventh internode becomes 52.9, 65.9, and 69.3 for the grain, grain-forage, and forage type sorghum, respectively. These latter percentages more nearly approach those which were found for the location of



[1]The grain and grain-forage types had no more than 12 internodes above ground level.

Figure 1. Per cent of the pupal cases taken from various parts of the plants of the different types of sorghum.

all stages in the plants as reported for the earlier dissection.

Table 9. Number and per cent of the pupal cases and immaculate larvae found in or below the seventh internode of sorghum.

	Type of Sorghum		
	Grain	Grain-Forage	Forage
Total number of pupal cases	105	66	136
Per cent of pupal cases in or below the seventh internode	40.7	54.5	58.2
Total number of immaculate larvae	50	28	47
Per cent of the immaculate larve in or below the seventh internode	78.0	92.9	100.0
Total number of all forms	155	94	183
Per cent of total forms in or below the seventh internode	52.9	65.9	69.3

Sorghum infested during the boot to grain-filled stage. Data relating to location of larvae on or in the plants of the variety Redlan, recorded from the dissection of five plants at different intervals after egg deposition, are given in Table 10. Data taken from the other four varieties were not tabulated because survival was low; therefore, field data were fragmentary. These data were recorded from the same plants as described previously under development and survival of summer form larvae.

Larvae of the three early instars, found on the variety Redlan, were usually located in the partially enclosed head or boot of the plants. Where the heads of the plants were exposed, however, these larvae were located under the sheath of leaves, occasionally as low as the third internode above ground level. Apparently they were feeding on the more tender and succulent inner portion of the leaf sheaths. As indicated in Table 10, larvae found within the stalks were of the fourth or subsequent instars.

The records obtained on the remainder of the varieties were in general agreement with those taken from Redlan. The general trend on all varieties was that the early instar larvae fed on any tender or succulent plant tissue above the ground level, with no larvae tunneling within the stalk until the fourth or subsequent instars.

Table 10. Location of different instar larvae as found on or in the plants of the variety Redlan, infested while in the boot stage.

	Location															
	Below	Internode Number													Pe-	
Instar	Ground	1	2	3	4	5	6	7	8	9	10	11	12	Boot	duncle	Head
I									1					2		
II				1										2	2	
III							1	1							2	1
IV				1	1	2	1*	1	1	1			1		2*	
V	1*									2*					1*	
VI		1*							1*			2*				

*Designates larvae in tunnels within the stalks.

<u>Sorghum infested during the mature stage</u>. From dissection of 80 plants of each variety, 73 to 78 days after egg deposition, some evidence of the difference in location of larvae was found among the various types of sorghum. Of all the larvae recovered or assumed to be present because of girdled plants, 45.5, 42.8, and 69.9 per cent were found below ground

level in plants of the grain, grain-forage, and forage types of sorghum, respectively. It is believed that food content of the plants, along with other factors, may have influenced the larvae to move to the location in which they were found. Side branches of secondary growth were about the only green parts of the grain type sorghum present at the time of dissections. Most of the larvae were located in the lower ends of these side branches and it is believed that some of them were preparing to overwinter there because several immaculate larvae were recovered from these positions. The forage type varieties had green tissue in the stalks at the time of dissections. Perhaps this plant tissue provided for more rapid larval maturity; therefore, the larvae had more time to tunnel to the portion of the plant below ground level. The grain-forage type variety also had green tissue in the stalks but to a lesser extent. The records were so few, however, that conclusions could not be drawn concerning the location of larvae in this variety.

Overwintering of larvae

Location in plants. Data on the location of immaculate larvae as found from the dissection of 90 plants of each variety infested while in the vegetative stage are presented in Table 11. These data, taken during the week of October 27, indicated considerable differences among the various varieties as to location of the immaculate larvae. There appeared to be some correlation between plant height and the location of larvae in the plants. The per cent of the larvae found below ground increased with the height of the various varieties. Darset, the variety having the shortest stalk, had only 53.5 per cent of the larvae located below ground. The remainder of the varieties increased in the per cent found in the plant below ground according to their respective heights, with Sugar Drip, the tallest variety having 94.4 per cent of all immaculate larvae located in this plant portion. Many of the immaculate larvae in the three shorter varieties were located above the ground in side branches where they had apparently prepared for hibernation. This was found to be especially so in the variety Darset.

Table 11. Location of immaculate larvae as found during the week of October 27 on sorghum infested when in the vegetative stage.

Larvae	Redlan	Darset	Hegari	African Millet	Sugar Drip	Total or Average
Total number	22	28	28	29	18	125
Number below ground[1]	13	15	22	27	17	94
Per cent in crown	59.1	53.5	78.6	93.1	94.4	75.2
Number above ground level	9	13	6	2	1	31
Per cent above ground level	40.9	46.5	21.4	6.9	5.6	24.8

[1]It was assumed that each girdled plant contained one immaculate larvae.

Mortality. No difference was observed in the varieties relative to the mortality of larvae. Data in Table 12 show the progressive increase in mortality of larvae located in the above ground portion of the plants as the winter season progressed. The 100 per cent mortality of these larvae as found in the last two dissections may be attributed to an onset of colder temperatures, since no immaculate larvae were found dead during the November dissection.

The larvae located in the portion of the plants below the ground level were affected to a much lesser degree than those in the above ground portion of the plants. Data showing the progressive rate of mortality of all larvae below the ground, both in girdled and standing plants, are given in Table 13. Only 3.8 per cent of the larvae found below ground on November 3 were dead, but by January 26, 37.5 per cent mortality had occurred.

Table 12. Mortality of immaculate larvae above the ground level in standing plants found through periodic dissection during the winter.

Larvae	Date of Dissection			
	Nov. 3	Dec. 1	Dec. 29	Jan. 7
Total number	32	26	19	10
Number above ground level	6	6	2	2
Per cent above ground level	18.8	23.1	10.5	20.0
Number above ground level dead	0	4	2	2
Per cent mortality above ground level	0	66.6	100.0	100.0

Table 13. Mortality of immaculate larvae below ground, in both girdled and standing plants, found through periodic dissection during the winter.

Larvae	Date of Dissection			
	Nov. 3	Dec. 1	Dec. 29	Jan. 26
Total number	32	26	19	10
Number below ground	26	20	17	8
Per cent below ground	81.2	76.9	89.5	80.0
Number dead below ground	1	2	2	3
Per cent mortality below ground	3.8	10.0	11.8	37.5

The greater part of the mortality which occurred in the plant portion below ground can possibly be attributed to larvae which died while attempting to overwinter in this portion of standing plants. As shown in Table 14, only three of 65 larvae recovered from girdled plants during all of the dissections were dead. Of these three, two were not found tunil the last dissection on March 23. Although these data are based on relatively small samples, they are believed to be nearly accurate because of the consistent rate of mortality found for the larvae in both girdled and standing plants.

Further indication of the greater rate of mortality in standing plants was found by dissection of approximately 450 plants during the period of pupation in the spring. Only four pupae and seven larvae were recovered from these plants. Because of the great amount of rainfall during the spring months, and the resulting deterioration of the standing plants, it was not deemed feasible to record data relative to larval survival.

Moisture accumulating in some of the plants below ground may have decreased the chance of survival for some of the overwintering larvae. Data given in Table 15 indicate a pronounced difference in the rate of mortality of larvae which were found in wet and in dry underground plant parts. The percentages as shown for the different dates of dissection are not consistent with the progression of the winter season. It is believed, however, that this factor had an important role in causing mortality of larvae, directly or indirectly, either by forcing them above the ground level where they were exposed to unfavorable conditions, drowning them, or by causing a reduction of temperatures in the below ground portion of the plants to an extent they could not

Table 14. Comparative mortality of immaculate larvae attempting to hibernate in underground parts of girdled and standing plants as found from periodic dissections through the winter.

Larvae	Date of Dissection Nov. 3	Dec. 1	Dec. 29	Jan. 26	Feb. 23	March 23	Total or Average
Total number below ground	26	20	17	8	15	12	98
Total number below ground dead	1	2	2	3	1	5	14
Per cent below ground dead	3.9	10.0	11.8	37.5	6.7	41.7	14.3
Number in girdled plants	15	12	14	4	12	8	65
Per cent in girdled plants	57.6	60.0	82.4	50.0	80.0	66.7	66.3
Number dead in girdled plants	0	0	1	0	0	2	3
Per cent dead in girdled plants	0	0	7.1	0	0	25.0	4.6
Number in standing plants	11	8	3	4	3	4	33
Number dead in standing plants	1	2	1	3	1	3	11
Per cent dead in standing plants	9.1	25.0	33.3	75.0	33.3	75.0	33.3

survive. It was noted that some of the dead larvae removed from standing plants which contained water in the underground parts, were found in the first few internodes above ground level.

Table 15. Comparative mortality of immaculate larvae occurring within dry and moist underground plant parts as found during periodic dissections throughout the winter.

Larvae	Date of Dissection					Total or
	Dec. 1	Dec. 29	Jan. 26	Feb. 23	March 23	Average
No. in plants moist below ground	10	3	3	3	6	25
No. dead	2	1	3	1	5	12
Per cent dead	20.0	33.3	100.0	33.3	83.3	48.0
No. in plants dry below ground	10	14	5	12	6	47
No. dead	0	1	0	0	0	1
Per cent dead	0	7.1	0	0	0	2.1

Twenty-two of the 33 standing plants, which had larvae removed from them during the winter, were found to contain various degrees of moisture. Ten of the 11 dead larvae removed from standing plants during the winter were found in these 22 plants having moist underground parts. All of the girdled plants in which dead larvae were found had a high moisture content.

Overwintering brood spring emergence

Survival. One-hundred and nine girdled sorghum plants remained in the field throughout the winter. Sixty-nine per cent of these stubs contained larvae which developed to adults. From 50 girdled corn plants, only 62 per cent contained larvae which developed to this stage. The fate of the overwintering larvae in these crops is shown in Table 16. Apparently the degree of mortality of larvae which occurred in both crops during the winter and early spring months was about the same; although, there was approximately seven per cent more mortality of pupae in corn than in sorghum. Statistically, using the "t" test as outlined by Snedecor (1956), at the 0.05 level, no significant difference was found in borer survival through moth emergence for the two crops.

Table 16. Fate of overwintering larvae in girdled plants of sorghum and corn.

	Sorghum		Corn	
Number	Number	Per Cent	Number	Per Cent
Girdled plants	108	100.0	50	100.0
Moths emerged	73[1]	67.1	31[2]	62.0
Dead moths in stubble	2	1.9	0	0.0
Dead pupae	12	11.1	9	18.0
Dead larvae	4	3.7	2	4.0
Girdled plants containing nothing	17	15.6	8	16.0

[1]One moth emerged before cages were placed over the girdled plants.
[2]Four moths emerged before cages were placed over the girdled plants.

Survival of the overwintering brood through spring moth emergence in the different varieties of sorghum is shown in Table 17. Moths emerged from all varieties, with the least survival found in Hegari. This variety showed only 45.5 per cent survival of the larvae which attempted to overwinter in it. African Millet provided conditions more suited to survival of larvae in the girdled stalks, followed by Redlan, Darset, and Sugar Drip. However, taking into consideration the difference in the number of larvae which girdled plants of the various varieties, it is believed that there is more potential of larvae overwintering on Sugar Drip than either of the grain type varieties.

Table 17. Survival of overwintered larvae through moth emergence from girdled plants of the various sorghum varieties.

Variety	Number of Girdled Plants	Number of Moths Emerged	Per Cent Survival
Redlan	11	8	72.7
Darset	9	6	66.6
Hegari	11	5	45.5
African Millet	47	36	76.6
Sugar Drip	30	18	60.0

Time of spring emergence and proportion of the sexes. In this study, spring moth emergence from sorghum began sometime before May 22 and ended June 17. On corn it began prior to May 25 and ended June 13. It was found by dissection of the girdled plants, from which no moths emerged, that four moths had emerged from corn and one from sorghum prior to placing the cages over the girdled plants. The proportions of the sexes of the overwintering brood which emerged from sorghum and corn are shown in Tables 18 and 19, respectively. The larger proportion of moths which emerged from both crops during the first third of the period of emergence were males, while during the second third the sexes were about equal and moths emerging during the last third of the period were predominantly females. Of the 72 moths emerging from sorghum, the over-all proportions of sexes was about equal, with 48.6 per cent females and 51.4 per cent males. The sex ratio, as found of 27 emerged moths from corn, was similiar to that of sorghum with 48.1 per cent females and 51.9 per cent males.

Table 18. Proportions of sexes of the overwintered brood which emerged from sorghum.

Date[1]	Males		Females	
	Number	Per Cent	Number	Per Cent
May 25	1	100.0	0	0.0
May 26	2	100.0	0	0.0
May 30	2	40.0	3	60.0
May 31	1	100.0	0	0.0
June 1	4	57.1	3	42.9
June 3	2	66.7	1	33.3
June 4	2	66.7	0	33.3
June 5	4	100.0	0	0.0
June 6	7	50.0	7	50.0
June 8	1	33.3	2	66.7
June 9	3	50.0	3	50.0
June 10	6	50.0	6	50.0
June 11	1	16.6	5	83.4
June 13	1	25.0	3	75.0
June 17	0	0.0	1	100.0

[1]No emergence occurred on dates not recorded.

The data were analyzed to determine if there was correlation of the date of girdling with either borer survival or date of spring emergence.

No evidence was found that the larvae which girdled plants at any particular time had a greater probability of survival or that difference in the time of girdling affected the date of spring emergence.

Table 19. Proportions of sexes of the overwintered brood which emerged from corn.

Date[1]	Males		Females	
	Number	Per Cent	Number	Per Cent
May 30	2	100.0	0	0.0
May 31	2	100.0	0	0.0
June 2	4	100.0	0	0.0
June 4	2	66.7	1	33.3
June 6	1	20.0	4	80.0
June 9	1	33.3	2	66.7
June 10	2	33.3	4	66.7
June 13	0	0.0	2	100.0

[1]No emergence occurred on dates not recorded.

Oviposition of overwintering brood

Extent of egg deposition. Twenty-nine of the 31 females which emerged from sorghum deposited eggs. Data on the fertility and fecundity of these females along with those which emerged from corn are presented in Table 20. A test of significance at the 0.05 level, showed no significant difference in the average number of eggs deposited by fertile females which emerged from the two crops. By the same method there was no significant difference in the average number of eggs deposited by females which deposited some fertile eggs and those which deposited only infertile eggs.

Table 20. Fertility and fecundity of female moths emerging from sorghum and corn.

Fertility and fecundity	Sorghum	Corn
Number moths	35[1]	8
Number depositing eggs	32	7
Number eggs deposited	10,103	2,643
Average eggs deposited	315.4	377.5
Number moths fertile	25	7
Number eggs deposited	8,263	2,643
Average eggs deposited	330.5	377.5
Average eggs fertile	289.4	351.0
Number moths infertile	7	
Number eggs deposited	1,840	
Average eggs deposited	262.9	

[1]Two moths died within two to four days without depositing eggs and records were not kept on one moth.

Females from sorghum deposited both the largest and smallest number of eggs per individual, showing a range of over 500 eggs (Table 21). The data in this table also show a range of the per cent of fertile eggs deposited by fertile females. The upper limit of this range for individuals from both crops is nearly equal, but the lower limit shows approximately 25 per cent less fertile eggs deposited by the individual emerging from sorghum.

Time of deposition. Egg deposition occasionally occurred during the first night after moth emergence, but in all cases these eggs were infertile. As shown in Figure 2, fertile moths deposited over 40 per cent of their eggs the second night after emergence. Deposition then declined steadily until the sixth night when only about one per cent of the total eggs was deposited. Infertile moths were found to distribute their egg deposition more evenly over a longer period of time, sometimes depositing as long as the eighth night after emergence.

Table 21. Range of fecundity and fertility of individuals from 22 fertile females overwintered on sorghum and seven overwintered on corn.

	Sorghum	Corn
	Number of Eggs	
Maximum fecundity	580	520
Minimum fecundity	76	247
	Per Cent of Eggs	
Maximum fertility	97.60	98.64
Minimum fertility	59.05	83.45

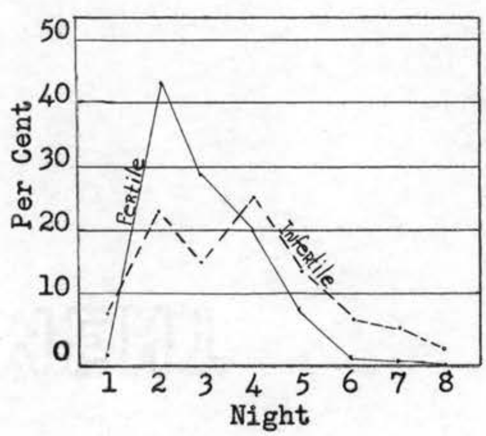


Figure 2. Comparison of the total output of eggs from fertile and infertile females from sorghum during each night after emergence.

The highest percentage of fertility was found for eggs deposited the third night after emergence, with approximately 96 per cent fertile. Figure 3 shows the consistent decline in the per cent fertility of eggs after the third night with moths depositing no fertile eggs on the eighth night.

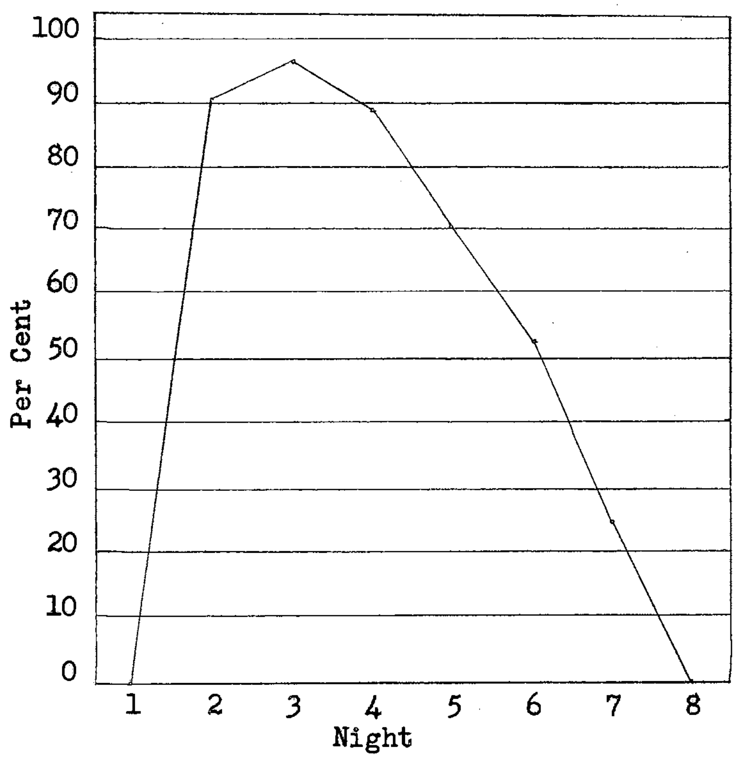


Figure 3. Per cent of the eggs deposited on each night after emergence which were fertile.

Data on Table 22 show the number of females which deposited eggs during each night after emergence with the number and per cent of the total egg output which were fertile. It was found occasionally that a female would deposit freely the first or second night, fail to deposit for one night, and continue during the nights thereafter.

Longevity of overwintered brood adults

A comparison of the longevity of both sexes of moths as found on sorghum and corn under laboratory conditions is shown in Table 23.

Both the minimum and maximum number of days longevity for females was found to occur for moths which emerged from sorghum, being 2 and 10 days, respectively. An average longevity of about five and one-half days was found for both sexes from the two crops.

Table 22. Egg deposition and fertility by number and per cent each night after moth emergence, as found from 22 fertile moths which had overwintered on sorghum.

Day	Number of Moths Depositing	Total Eggs	Number Fertile	Per Cent Fertile
1	6	45	0	0.00
2	17	2,976	2,723	91.49
3	19	2,208	2,066	96.13
4	20	1,646	1,471	89.36
5	17	560	399	71.25
6	6	84	45	53.57
7	2	15	4	26.66
8	1	1	0	0.00

Table 23. Longevity in days of moths overwintered from corn and from sorghum.

Longevity	Sorghum		Corn	
	Males	Females	Males	Females
Number of moths	37	34	4	8
Minimum longevity	2	2	4	3
Maximum longevity	8	10	8	7
Average longevity	5.35	5.68	5.75	5.25

CHAPTER V

DISCUSSION

All sorghum varieties provided conditions suitable for development and survival of Z. grandiosella Dyar. Rolston (1955) found that this borer required an average of 39.6 days to complete larval maturity on sorghum when reared in an insectary. Data in Table 2 show a considerable variation in length of time required for larval maturity in the field, as all stages from fourth instar larvae through emerged moths (pupal cases) were observed 38 to 40 days after egg deposition. Data in Table 5 indicate variation of development and survival of this borer among varieties. Six instar larvae were found in the variety Redlan 36 days after egg deposition while Hegari had larvae of only the fourth instar at 34 days. Similiar variation was also found in the varieties Darset, African Millet, and Sugar Drip.

Rate of development for the various larval instars found on Redlan is comparable to that on corn as found by Hensley (1955). He pointed out considerable variation on corn with first instar larvae found 3 to 7 days after hatch; second instar, 3 to 11 days; fourth instar, 13 to 24 days; fifth instar, 19 to 24 days; sixth instar, 20 to 30 days; and pupae, 20 to 36 days.

Survival on sorghum was found by Rolston (1955) to be nearly equal to that on corn. Survival of the first generation on corn, in Oklahoma, was estimated by Hensley (1955) at 32.9 per cent. The present study indicates that from about 17 to 25 per cent of the larvae which hatched on vegetative stage plants of the different varieties of sorghum developed successfully and emerged as adults (Table 4).

Survival apparently decreases for borers attempting to establish on older and tougher plants. Table 6 shows that about one-eighth as many borers survived on plants infested when at or near maturity as on those infested while in the vegetative stage (Table 4). Hensley (1955) found a low survival of borers (approximately four per cent) of the second generation which he attributed to drought-damaged plants.

Data shown in Table 5 indicate the greatest mortality of borers occurs about the time of establishment on the plants, since only 30 per cent of the larvae which hatched on the plants were recovered six days after egg deposition. By the time sixth instar larvae were found on the variety Redlan, only 20 per cent of the larvae which had hatched on the plants were recovered. This indicates that about 10 per cent of the mortality of larvae which hatched on the plants occurred between the first and sixth instar on the variety, but on Hegari approximately 20 per cent of the total mortality was found to occur between these two larval instars. Apparently mortality on sorghum is similiar to that on corn as Hensley (1955) reported that approximately two-thirds of the larvae failed to survive through the first instar and that little mortality occurred in the last five instars or the pupal stage. Survival was consistently lower through all larval instars for Darset, African Millet, and Sugar Drip with extremely small numbers of larvae being recovered during each dissection.

Walton and Bieberdorf (1948) found third generation larvae about two-thirds grown on October 2, in Oklahoma. Here, girdled plants were found and live sixth instar larvae were recovered on November 16 and

November 21 from plants infested with eggs deposited August 31 through September 8 (Table 6). Although the per cent survival is not known for the borers in the girdled plants infested at these late dates, data taken during the spring showed moths did emerge.

There was some variation in the location of borers in the plants of the different sorghum types (Table 7 and Figure 1). This variation appears to be correlated somewhat with the height of the plants since the per cent of total stages and forms found above the seventh internode are consistently less in the taller types. The data in Table 8 are not consistent in this respect but those of Table 9 are in agreement with Table 7.

As suggested by Hensley (1955), apparently the locations of larvae within the plants depend on their stage of development and the type of plant tissue required by them. Larvae through the third instar recovered from Redlan, infested while in the boot stage, were found beneath the leaf sheaths enclosing the peduncle or internodes of the stalk, in the boot, and in the extruded head of the plants (Table 10). Larvae found tunneling within the stalk were all of the fourth or subsequent instars. Hensley and Arbuthnot (1957) found that on whorl stage corn, early instar larvae with few exceptions fed in the whorl of the plants but as whorls opened and these tissues became tougher and less moist, they preferred any part of the plants above ground that were tender and moist. Further evidence concerning the relationship on plants to food suitability is given in the records of larvae recovered from plants infested after maturity. Sixth instar borers were found distributed from the underground parts of the plant to the peduncle. After plants of the variety Darset matured, side branches grew from the above-ground nodes. As shown in Table 11, approximately 54 per cent of the immaculate larvae in this variety were above ground level with most of them in these side branches which contained relatively tender tissues.

During the early winter mortality observations, approximately 19 per cent of all the immaculate larvae recovered were found in plant parts above ground level (Table 12). Comparison of mortality of these larvae to those located in the below ground parts (Table 13) shows that by December 29, 100 per cent mortality had occurred for larvae above the ground level. Indications are that larvae attempting to hibernate in the above ground portion of the plants have little chance for survival through the winter.

Evidently girdling of the plant by this borer increases its chance of survival through the winter. Comparison of mortality between immaculate larvae located below ground in girdled and standing plants (Table 14) shows an average of seven times more mortality of larvae in standing plants than in those girdled. A considerable amount of the mortality found within this comparison can possibly be attributed to moisture in the underground portion of the plants. Consolidation of data in Table 15 indicates that 92.3 per cent of all the dead larvae recovered from December 1 until March 23 were found in moist plants. It is believed that high moisture content causes the larvae to move upward in the standing plants to above ground level where they are more exposed to unfavorable fluctuating temperatures.

Of the 1,900 plants infested during this study and left remaining in the field until October 27, 1956, to afford larvae an opportunity to girdle, 182 were girdled accounting for about 9.7 per cent girdling. The greatest amount of girdling occurred on plants infested July 22 through July 31, and August 10 through August 13, with 12.3 and 12.4 per cent, respectively. The plants which were infested July 6 through July 10, and September 2 through September 12, showed 8.2 and 2.2 per cent girdling, respectively. This indicates that the greater percentage of girdling of sorghum would be accomplished in the natural state by larvae of the second or possibly the third generation. The time of the manual infestations on those dates corresponds to the natural second and third generation of this borer as reported by Walton and Bieberdorf (1948).

Wilbur et al. (1950) pointed out that examination of infested corn and sorghum in January, 1943, revealed only 35 per cent of the borers in sorghum were yet alive as compared to about 70 per cent of those in corn. Rolston (1955) in May, 1954, found survival as high as 72 per cent in girdled stalks of corn in Arkansas. Of the 182 sorghum plants which were girdled, 108 were left in the field throughout moth emergence in the spring. Data from these girdled plants indicate that about 67 per cent of the larvae which attempted to overwinter survived to adults, while about 11 per cent survived through pupation and then died. A comparison with corn in Table 16 discloses little difference in survival of this borer on the two crops. Corn afforded conditions suitable for 62 per cent survival to adults, while 18 per cent died after surviving through pupation. Apparently the potential of this borer overwintering on sorghum in this area after it has girdled the plant, is as great as on corn, although the extent of girdling on sorghum is much lower than the 60 per cent reported by Rolston (1955) on corn in Arkansas for 1953.

The different varieties of sorghum apparently vary in affording suitable conditions for this borer to overwinter as shown in Table 17.

Hegari, showing the least survival of borers had only about 46 per cent of the larvae surviving through moth emergence, while African Millet had about 76 per cent. Since over three times as many plants were girdled in the two forage type varieties as the two grain types, it is believed that the differences in survival were due to the differences in per cent of girdling between the two types of sorghum.

Davis et al. (1933) stated that emergence of both sexes starts approximately at the same time in the overwintered generations and that the ratio of males to females remains fairly constant throughout the season, the females always being present in larger numbers. Data in Tables 18 and 19 show that on both sorghum and corn the male population was predominant during the first one-third of the period of emergence with 4 to 5 days elapsing after the first male emerged before females appeared. The sex ratio of total emergence was similiar to that found by these authors with exception of the males being slightly predominant from both crops, with approximately 49 per cent females, 51 per cent males.

Davis et al. (1933) reported an average of 246 eggs deposited by female moths with as high as 99 per cent fertility. Rolston (1955) reported an average of 147 eggs each for 20 overwintering brood females. Table 20 shows an average of about 331 eggs deposited by fertile moths from sorghum and about 378 from those on corn. Since data in this study were taken from moths depositing under caged conditions as well as data by previous investigators along this line, it is believed that variations in environmental conditions provided for the moths may have influenced the number of eggs deposited. Table 21 shows a range of the number of eggs deposited by individual moths from both crops. The upper limit of this range as well as egg fertility for moths from both crops is similiar to that found by Rolston (1955) from moths reared on corn.

Egg deposition the first night after emergence of moths occurred several times but in all cases the eggs were infertile (Table 22). The greatest percentage of egg deposition by fertile moths was found to occur the second night after emergence (Figure 2) but the highest percentage of the total eggs deposited during one night which were fertile was found on the third night (Figure 3). After the third night both fertility and the number of eggs deposited by the females appear to decline; however, egg deposition by one female was observed to continue into the eighth night after emergence. Infertile females deposit considerably fewer eggs and tend to distribute deposition more evenly over a period of about 5 to 8 days (Figure 2).

Data on the longevity of both sexes taken from sorghum and corn (Table 23) show little difference for either sex; all data being comparable to that reported by Rolston (1955). Males and females from both crops had an average longevity of about five and one-half days.

CHAPTER VI

SUMMARY

A study was made at Oklahoma State University at Stillwater, Oklahoma from June, 1956 to June 1957, to determine the potential of the southwestern corn borer, Z. grandiosella Dyar to develop and overwinter on sorghum. Five varieties of sorghum which are commonly grown in Oklahoma were manually infested at four different ages during the summer of 1956. These varieties were Redlan, Darset, Hegari, African Millet, and Sugar Drip.

Results indicated that the summer generations of this borer could develop and survive on all varieties; although, survival was never higher than 26.5 per cent. Apparently, of the five varieties, African Millet affords conditions best suited for development and survival.

Early instar larvae were found either in the whorl of the plants or if no whorl was present they were located under the leaf sheaths. It was not until they had reached the fourth instar that they were found in tunnels in the stalks. The greater per cent of the latter instars were located in or lower than the seventh internode of the plants.

Approximately 19 per cent of all larvae which attempted to overwinter were located in plant parts above ground level. These larvae did not survive through the winter. Moisture which accumulated in the underground portion of some plants, apparently had a devastating effect in many cases on the overwintering larvae. All of the girdled plants in which larvae were found dead during the winter, had a high moisture

content.

About 9.7 per cent of the total sorghum plants, infested throughout the summer and left in the field to allow for girdling, were girdled in preparation for overwintering by the larvae. The survival of overwintered larvae in these girdled plants was high and is comparable to that found in corn.

The proportion of the sexes of the overwintered brood from both sorghum and corn was about equal. Statistical analysis showed no significant difference between the number of eggs deposited by females from sorghum and corn; although, in general those from sorghum produced fewer eggs. The rate of egg deposition was found to be the greatest on the second night after moth emergence; although, the grestest percentage of fertile eggs was deposited on the third night.

Little difference was observed between the longevity of either sex from sorghum or corn, all averaging from 5.25 to 5.75 days.

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