

THE EFFECTS OF INSECT POPULATIONS ON SEED  
PRODUCTION/OF Sorghum vulgare (Pers.)

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PRODUCTION OF *Sorghum vulgare* (Pers.)

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## PREFACE

The need for a profound study on the relationships of the major sorghum insect pests to sorghum yield was brought to the author's attention while working under the supervision of Mr. C. F. Henderson, Leader Small Grain Insects Investigations, Entomology Research Division, U. S. Department of Agriculture, Stillwater, Oklahoma. It was decided that this study would make an interesting and worthwhile thesis problem.

The author is deeply indebted to Mr. Henderson, major adviser, for his constant interest in the study, help in planning and executing the experiments, and careful criticism of this manuscript. Special thanks are also extended to Mr. Frank F. Davies of the Agronomy Department who arranged for and planted the majority of the field plots used in most of the experiments contained herein and provided many valuable suggestions. Without the assistance, cooperation and encouragement of these two men, this work could not have been conducted.

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## INTRODUCTION

Many writers have called attention to the need for precise quantitative data on insect losses. Decker (1955), for example, stated that "most of the currently available information on the magnitude of agricultural and other losses attributed to insects is at best a compilation of estimates which may or may not deserve the title of 'educated guesses'." Despite pleas such as these, there exists very little accurate information on the effect of insect populations on the yield of agricultural products.

In many insect control operations, the obvious consideration is the economic gain or the portion of the crop that will be saved by control practices less the cost of control. Therefore, precise data on the potential effect of population densities on yield are necessary to predict whether or not control practices are economically feasible under a given set of environmental conditions.

Currently, adequate control procedures are available for a majority of the economically important pest species. Consequently, insecticides are often indiscriminately applied as soon as a pest is detected, without consideration of what represents an economic population. This is especially true with "cash crops" such as cotton, wheat,

corn, etc. Such practices present a less obvious, but perhaps more important consideration in control operations, viz., the possibility of accelerating the development of insecticide-resistant insect strains. Hastings (1960) pointed out that this type of practice could result in the loss of means for controlling economically important species, and suggests that it seems wiser to tolerate a small amount of damage over an extended period of time rather than none for a short time followed by the problem of having no available control.

Carefully planned control programs based on reliable data would not only save money for the producer, but would also contribute to the future of agriculture as a whole.

The acquisition of such data is no easy task, as exemplified by its scarcity. Extensive research by trained personnel in all phases of entomology will be required to furnish the needed information.

The purpose of this work was to determine the effect of various population levels of the major sorghum pests on the yield of grain sorghum.

Grain sorghums are thought to have originated in Africa. Today, they rank third as a world food grain, being the chief grain consumed in parts of India, China, Manchuria, and Africa. Approximately eighty million acres annually are devoted to their production throughout the world (Quinby, 1958).

Grain sorghum achieved a cash crop status in the United States due to the development of adapted sorghum varieties that could be harvested mechanically and the increased demand for grain during World War II. More recently, increased yields due to the development of hybrids and to acreage controls on cotton and wheat have resulted in the planting of increased acreages of sorghum. Today it is the fourth ranking agronomic money crop, exceeded only by cotton, wheat and corn. This recent increase in sorghum acreage has been accompanied by increased insect problems.

Insect control is often more critical for grain sorghums than for other cash crops, because of the relatively low per-acre value of sorghum and consequently a lower margin of profit. The application of control practices, such as two or three insecticidal treatments per year, might take away the grain sorghum producer's profits. For this reason, entomologists in an advisory capacity are frequently confronted with the question "What is an economic population under a particular circumstance?" This study should help furnish information as to what constitutes an economic population of some of the more important sorghum pests, and to contribute added knowledge as to their biology.

Consequently, work was begun during the summer of 1959 to develop techniques for measuring the effects of insect populations on yield of grain sorghum. An attempt



was made during the 1959 season to regulate populations by artificially infesting heads covered with paper "selfing bags." The bags proved unsatisfactory for confining earworm larvae because of their ability to chew holes in the paper and escape. Webworms remained caged; however, the humid condition created by the bag promoted a heavy growth of undesirable fungi on the heads, making the recovery of the pupae impracticable. During that season, a method of regulating sorghum webworm populations by applying various levels of a highly volatile insecticide, Phosdrin<sup>1</sup>, was developed and successfully used to measure the effect of various population densities on yield. Population regulation by insecticides proved unsatisfactory for corn earworm larvae, because of the great population fluctuations occurring under natural conditions.

It became apparent that an accurate determination of damage by the corn earworm would require the employment of a cage capable of preventing the escape of larvae and the entry of natural enemies without altering the environment within the sorghum heads. In the 1960 season, a preliminary corn earworm damage test was conducted in which a cylindrical screen wire cage with cloth sleeves was employed. This cage was satisfactory in that the larvae could not bore out, and the environmental condition was not visibly altered. However, one disadvantage was

<sup>1</sup>Phosdrin (1-methoxycarbonyl-1-propen-2-yl-dimethyl phosphate) is a rapidly dissipating insecticide that has no appreciable residue 24 hours after application.

that the mesh was not small enough to retain first to third instar corn earworm larvae. Another factor disclosed in this test was that, in evaluating the damage due to a designated population, some compensation would have to be made for larvae that died rather than pupated.

Also, it became evident that the stage of sorghum preferred as food and the relative rate of consumption by the various instars would have to be determined. This information was necessary in order to infest test plots with the correct larval instar at the optimum stage of plant growth.

## REVIEW OF LITERATURE

Cartwright (1933) employed a method of comparing the weights of corn from infested and noninfested stalks to determine the damage due to the southern cornstalk borer, (Diatraea crambidoides (Grote)), in which the infestation rate did not exceed one or two larvae per stalk. On the basis of 51% of the plants infested in the field, he calculated a field loss of about 15%. In case of a 100% infestation, the yield loss would be approximately 30%.

The extent of damage due to insects of crucifers in relation to their population densities was studied by Prasad (1957). His data indicated that 20 aphids were required to show significant damage to 4-week-old cabbage plants, while 50 aphids per plant were required to demonstrate damage at 7 weeks. The potato leafhopper (Empoasca fabae (Harris)) showed a significant yield reduction at a population level of 20 per plant. The importance of the life stage of a particular insect in control problems was demonstrated by a 2.6 times greater yield reduction with leafhopper nymphs than with a comparable number of adults.

Studies conducted by Coaker (1959) in Uganda and McKinlay and Geering (1957) in Uganda and Tanganyika are

of interest. They were unable to demonstrate an increase in the yield of early planted cotton by controlling Lygus sp., even though these insects caused extensive shedding of the squares and bolls. The reason for this lack of yield reduction was due to the strong recovery power of the cotton plant, and the long growing season in these areas that made it possible for plants to produce additional fruit to replace the ones destroyed by Lygus.

Granular application of endrin at different treatment schedules was used by Floyd (1960) to secure a differential population of the sugarcane borer (Diatraea saccharalis (Fabr.)). Schedules allowing a high survival of the borer caused a reduction in yield, as well as in the grade of the corn, due to reduction in the number of primary ears, smaller ear size, and lower test weight. However, no attempt was made to correlate the number of borers with the resulting damage.

Ortman and Painter (1960) found that greenbug (Toxoptera graminum (Rond.)), infestations in wheat caused a maximum reduction of 55% of the plant root system, and that the above-ground plant parts were damaged to approximately the same degree.

In studying the damage caused by the corn earworm (Heliothis zea (Boddie)), Barber (1936) found that the average number of injured kernels per ear varied greatly, depending upon the characteristics of the shuck. Only 1.53% of the kernels were injured on ears enclosed in a

tight shuck extending three inches beyond the tip of the ears, whereas, 52.77% of the kernels were damaged on ears having a less well developed husk. The limiting factor associated with the tight husk was believed to be the cannibalistic larval habits under more crowded conditions.

In later studies, Barber (1943) observed that the corn earworm adult oviposited on all parts of the corn plant in all stages of growth, and that the larvae migrated to the silks as soon as they emerged. Prior to silk emergence they fed on tender whorl leaves and green tassels. Plant injury was correlated with the number of eggs deposited on the silks, but not with the total number of eggs deposited.

Chaing, et al, (1960), attempted to determine the relationship between summer and fall populations of the European corn borer (Pyrausta nubilalis (Hübner)) and their effect on yield. He pointed out that the summer population may be only a fraction of the fall population or vice versa, depending on the number of the first brood which pupated in the summer and on prevailing environmental factors. For this reason, the fall population should be used as a basis for assigning damage only when the summer population is very low.

Arbuthnot, et al, (1958) studied the effect of first generation southwestern corn borer larvae on yield of corn. It was found that infestation reduced plant height and yield. An attempt to establish differential population levels by artificially infesting with various numbers of

larvae was unsuccessful. An accurate measurement of the population was not attainable by plant dissections at harvest.

Wilbur, et al, (1943) described the injury to corn plants as due to the following: (1) feeding on the leaves; (2) feeding on or about the terminal bud within the whorl; (3) boring through the stalk; (4) boring into the shanks and ears; and (5) internal girdling of the stalk.

Work by Gifford, et al, (1961) indicated that sorghum may serve as an overwintering host for the southwestern corn borer. In grain-, grain forage-, and forage-type sorghums infested with corn borer larvae, the larval period was slightly longer than on corn. Some larvae attempted to hibernate in branches above the ground and were killed. The per cent larval emergence was about the same for sorghum and corn. He attributed the low natural infestation of sorghum to the unattractiveness of this host for ovipositing moths.

Wilbur, et al (1943) suggest that sorghum, although being infested by the southwestern corn borer, is resistant to its attack. Walton and Bieberdorf (1948) mentioned the possibility of side-stepping the corn borer problem by growing sorghum instead of corn. They also reported a negative correlation between corn yield and southwestern corn borer populations. In experimental plots, average yields of 23.8, 24.2, 16.3 and 3.0 bushels per acre were associated with average populations of 2.3, 2.8, 3.1 and

6.6 borers per plant, respectively.

Walter (1941) named the sorghum midge (*Contarinia sorghicola* (Coq.)) as the most important, as well as the most common cause of sorghum blight. He stated that "a single larva per spikelet is sufficient to cause the loss of the grain."

Doering and Randolph (1960) developed techniques for estimating damage to grain sorghum by the sorghum midge. The method used was the visual assessment of damage to individual heads by placing them into previously defined categories. This method proved to be effective when the damage readings were compared with actual yields. It may be useful in estimating midge damage to early-season sorghum, and thus aid in the prediction of heavy infestations in late-maturing sorghum.

Bigger (1958) described the affects of the corn leaf aphid (*Rhopalosiphum maidis* (Fitch)) on corn. He demonstrated that the percentage of plants that failed to bear fruit was increased by infestations of this insect.

In tests conducted by Everly (1960), consecutive corn plants in a heavily infested field were marked as either uninfested, lightly infested or heavily infested with corn leaf aphids. Twenty per cent of the heavily infested plants were barren. Ear weights averaged .54, .50, and .46 pound for the no-infestation, high-infestation, and heavy-infestation rates, respectively, when barren plants were not considered. When barren plants were

included, the yields for the respective categories were 72, 65 and 34 bushels per acre, or a loss in yield of 9.7% with the light infestation and 52.7% with the heavy infestation. The 9.7% loss associated with slight infestation is of significance, because, until this time, it was assumed that infestations not serious enough to cause barren plants had no effect on yields. Everly also pointed out that, in a test of this nature, the uninfested plants may have an advantage over adjacent infested plants, and, therefore, emphasize the loss that occurred.

It has been reported that germination of corn attacked by the corn leaf aphid was reduced approximately 5% (Hays, 1922).

The corn leaf aphid, as McCollock (1921) pointed out, must be regarded as a serious pest of sorghums as well as corn, and is present every year in most sorghum-growing areas causing obscure damage often attributed to other factors. Damage is due to feeding on the succulent leaves of the whorl stage and on the head as it develops. Following a corn leaf aphid attack during 1919 in western Kansas, the grain was so shriveled that the entire crop was ruined.

According to Bigger (1958), commercial corn hybrids differ in the degree of corn leaf aphid infestation and loss.



## TESTS WITH THE CORN EARWORM

### Heliothis zea (Boddie)

#### Consumption by Instar and Total Consumption of Corn Earworm Larvae

#### Materials and Methods

A test was conducted to determine the consumption by each instar and total consumption of sorghum by corn earworm larvae. This was done by placing a newly-hatched, first instar larva in a cage containing a freshly-picked and weighed sorghum branch. After a 24-hour period the larva was transferred by means of a camel's-hair brush to another cage, also containing a newly-picked and weighed branch. The branch on which the larva had fed for the 24-hour period was weighed after careful examination for, and removal of any frass adhering to the kernels. This procedure was replicated 20 times.

Ten check cages, identical to the others except that they were not infested with a larva, were set up daily. The average weight loss (or gain) to the atmosphere, as determined in the check cages, was added (or subtracted in the case of gain) to the difference between the initial weight of the sorghum branch and that after 24 hours. The value attained in this manner represented the net

consumption for a 24-hour period. A daily record was kept for each larva in this manner. The molts were also recorded.

The cage used (Figure 1) consisted of a 1 x 4-inch glass tube with a plastic cap and a split rubber stopper base. The cap had fine slits to insure air circulation. The split rubber stopper was used to hold the sorghum branch upright. Sorghum branches were picked early in the morning while still turgid. The developmental stage of sorghum fed to the larvae was selected on the basis of the larval instar, as determined by the stage preference tests (page 21).

It was anticipated at the outset that considerable mortality would occur in the first and second instars. In order to maintain a continuous daily record of consumption, "litter mates" were concurrently started on sorghum. When a larva died in one of the cages it was immediately replaced with a "litter mate" of the same instar and similar size. Weighing was accomplished with a Mettler H5 Multi-Purpose balance calibrated to  $\frac{1}{10}$  0.1 mg.

## Results

Total consumption by the first and second instars was slight, being .0853 and .0759 gram, respectively (table 1). As anticipated at the beginning of the test, considerable mortality occurred in the second instar.

The previously described larval replacement procedure used in cases of mortality probably resulted in a slightly inaccurate consumption record for the second instar and accounts for the lesser consumption than that of the first instar. Feeding increased almost by logarithmic progression from the fourth to the sixth instar.

Table 1. Consumption by instar and total consumption of sorghum by larvae of the corn earworm, Heliothis zea (Boddie). Stillwater, Oklahoma, 1961.

Instar	Average Consumption Per Larva (grams)	Per Cent of Total Consumption
1	.0853	1.8
2	.0759	1.6
3	.2981	6.2
4	.3533	7.4
5	.8330	17.4
6	3.1397	65.6
Total Consumption 4.7 grams per larva		

Total consumption for the entire larval period was 4.74 grams. Although this figure expressed "green weight", it is considerably less than the dry-weight consumption figures taken at harvest in later field tests. It was assumed that the unnatural environmental condition within the cage was responsible for this low consumption. Even so, apparently normal adults were obtained from all larvae completing the test.

## Conclusions

These data were of value in setting up field tests to determine the effect of population levels of corn earworms on the yield of grain sorghum. From these data it was assumed that infesting test plots artificially with third instar larvae would measure more than 95% of the damage possible by a corn earworm larva. A relatively high degree of mortality occurring in the first and second instars indicated that third instar larvae were the smallest that should be used to infest field plots.

## Developmental Stages of Grain Sorghum Preferred As Food by the Larval Instars of the Corn Earworm

## Methods

An experiment was conducted to determine the developmental stage of grain sorghum heads preferred as food by each corn earworm larval instar. The following developmental stages were selected for use in the test: (1), flowering; (2), milk, (3), soft dough; and (4), hard dough. All branches used in this test were picked early in the morning while the plants were still turgid. Branches selected to represent the flowering stage had freshly emerged anthers protruding from the glumes at the base of the branch and older anthers at the apex, i.e., the majority of the embryos had been fertilized the preceding day. Milk-stage

sorghum branches were picked after the flowering parts had dried and the developing embryos contained a watery material.

Branches representing the soft-dough stage were selected after the formation of a thick dough in the kernel, but before it had become hard enough to separate into small pieces when mashed. Kernels that separated into small pieces, or in which the two halves of the embryo divided when mashed, were classed as being in the hard-dough stage.

Several sorghum heads of different developmental stages were brought to the laboratory each morning, and the required number of branches representing the above four categories were selected. Four of the branches, one representing each category, were placed around the periphery within a cylindrical glass cage. Twenty to 30 such cages were infested daily with a single corn earworm larva. To reduce possible environmental effects, the branch positions were randomized and all of the cages placed in a uniformly dark enclosure. After a period of approximately 8 hours, the developmental stage of sorghum on which the larva was feeding was recorded. Cages constructed of 1 x 4-inch glass tubing (like the ones used for the larval consumption test, Figure 1) were used for the first and second instar larvae; whereas, cages of  $2\frac{1}{4}$  x  $2\frac{1}{2}$ -inch glass tubing were used for the third, fourth, fifth and sixth instars (Figure 2).

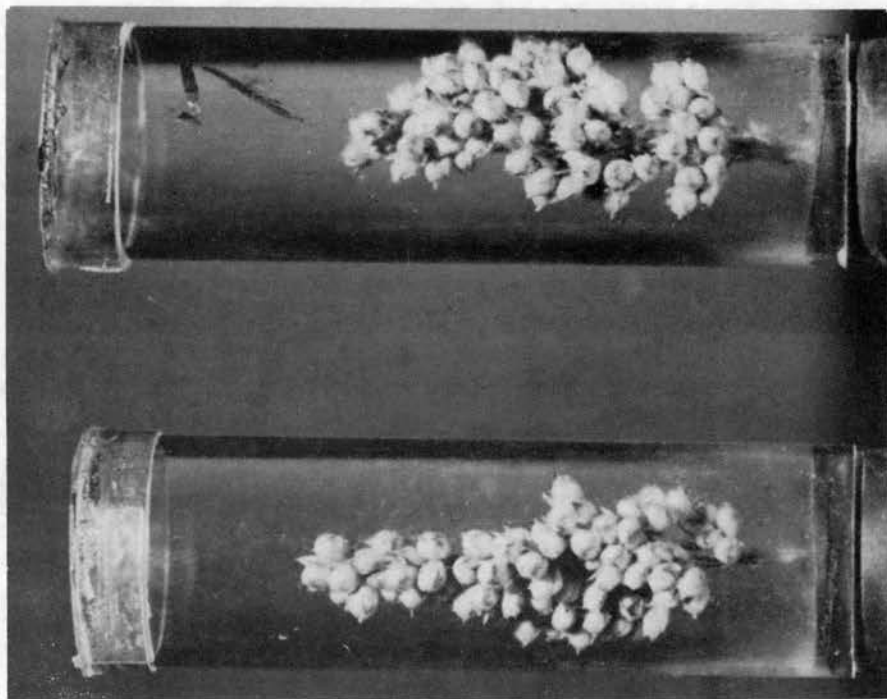


Figure 1. Cylindrical glass cage used to measure consumption by instar and total consumption of grain sorghum by corn earworm larvae.

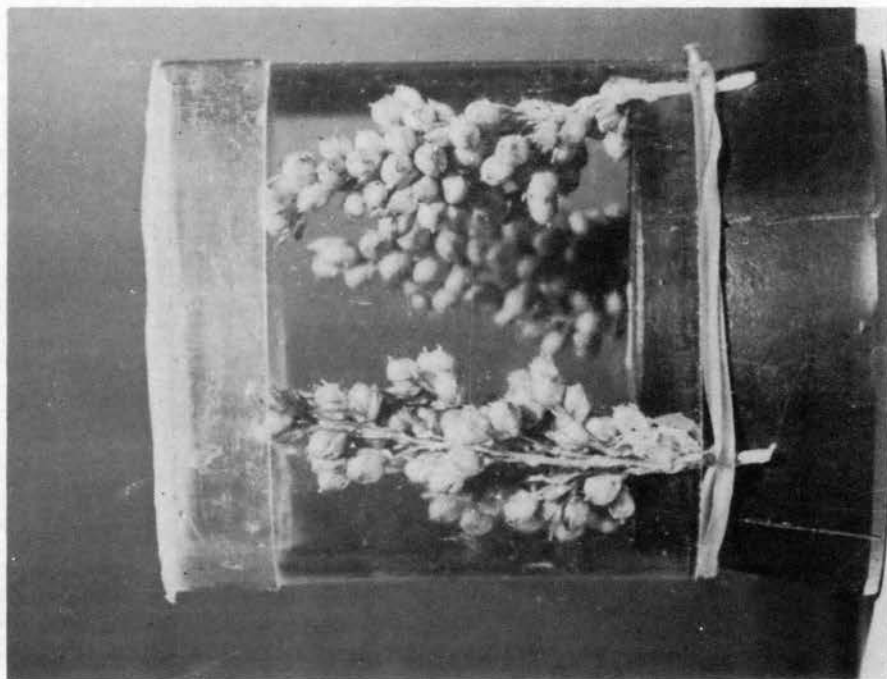


Figure 2. Glass cage used to determine feeding preference for larval instars of the corn earworm.

## Results

As shown in Table 2, the majority of the first instar larvae preferred the flowering stage as food. The second instar also preferred the flowering stage, although more were feeding on the milk stage than in the first instar. The third and fourth instars exhibited similar food preferences. Twenty-five per cent of the larvae were feeding on the flowering stage and 55% on the milk stage in each case. The fifth and sixth instar larvae also preferred the milk stage under the conditions of this test.

Table 2. Developmental stages of grain sorghum preferred as food by larval instars of the corn earworm, Heliothis zea (Boddie). Stillwater, Oklahoma, 1961.

Location of Various Larval Stages After 8 Hours						
Larval	Flowering	Milk	Soft-Dough	Hard-Dough	Actively Moving	Per Cent Dead
First*	78.6	3.6	0	0	17.9	0
Second*	52.2	17.4	8.7	0	17.4	4.3
Third**	25.0	55.0	5.0	5.0	10.0	0
Fourth**	25.0	55.0	10.0	0	10.0	0
Fifth**	10.0	65.0	10.0	15.0	0	0
Sixth**	15.0	50.0	0	0	30.0	0

\*1-inch diameter glass cage

\*\*2 $\frac{1}{4}$ -inch diameter glass cage

## Discussion

Due to the relatively small number of replications (20-30) the results of this experiment may represent only general trends. Small cages were used for testing larval feeding of the first and second instar, in order to have the different developmental stages of sorghum in close proximity and thus allow the small larvae a greater choice in selecting food material. The larger cages used to contain the larger more motile larvae permitted the use of larger branches and resulted in a more natural feeding situation. The high percentage of first and second instar larvae recorded as actively moving about in the cage was due to larvae crawling to the top of the cage and remaining there rather than on the branches. The large numbers of larvae that were recorded as moving about in the sixth instar was probably due to natural restlessness prior to pupation. Although these data indicated that the first and second instar larvae preferred the flowering stage, and the fourth, fifth and sixth, the milk stage, this type of feeding rarely occurs in the field. Field observations indicated that, by the time the fourth or fifth instar was reached, only the lower kernels remained in the milk stage. Consequently, the fourth, fifth and sixth instars actually feed on more advanced sorghum, i.e., in the soft- and hard-dough stages. In order to determine if drying of the kernels inside the cages was affecting results, one series of



cages containing fourth instar larvae was checked after 50 hours. Thirty-three per cent of the larvae were on the flowering stage, 55% on the milk stage, and 11% were moving actively in the cage. These results did not differ significantly from results of the 8-hour counts.

### Conclusions

These data indicated that the flowering stage of grain sorghum was preferred as food by first and second instar corn earworm larvae. The third, fourth, fifth and sixth instars preferred the milk stage, although by the time that the larvae reach the last three instars under field conditions, milk-stage sorghum is usually not available for consumption. Sorghum heads that have completed one-half to two-thirds of the flowering stage were in the best condition to infest with third instar larvae in field plots designed to determine the effect of population levels on yield. Both milk-stage (located at top of head) and flowering-stage kernels were present at this time.

## The Effect of Corn Earworm Population Levels on the Yield of Grain Sorghum

After the development of a successful caging technique, tests were initiated in the summer of 1961 to measure the effect of various population levels of the corn earworm, Heliothis zea (Boddie), on the yield of grain sorghum.

### Methods

The tests were conducted on the Agronomy Department experimental farm near Stillwater, Oklahoma. Six-row plots of RS-610 sorghum approximately 300 yards long were used for the tests. The first experimental field was planted May 10, 1961, and the second May 20, 1961.

When the plants reached a height of approximately four inches, they were thinned to 8 and 10 inches between plants for the first and second fields, respectively. As the heads began to emerge from the boot, a large number were caged to prevent natural infestation.

Cages made of 30x30-mesh lumite<sup>2</sup> plastic screen with a 4 $\frac{1}{2}$ -inch long cloth sleeve at the top and a 6-inch sleeve at the bottom were used (Figure 3). Both sleeves were equipped with a drawstring. As the heads began to emerge from the sheath, the bottom sleeve was fastened to the stem of the plant by wrapping loosely

<sup>2</sup>Produced by Chicopee Manufacturing Corporation, Cornelia, Georgia.



Figure 3. Cages made of 30x30-mesh plastic "lumite" screen used for the corn earworm yield test and others.

with 2-inch SCOTCH brand masking tape. As the head grew out at the boot, the tape was removed and the cage resealed by fastening the bottom sleeve drawstring immediately below the base of the head. When the heads were approximately half flowered, they were infested with third instar corn earworm larvae. Immediately before infesting with larvae, heads of comparable size were selected. It was found that the peduncle had the smallest diameter at a point approximately  $1\frac{1}{2}$ -inch below the bottom branch of the head. This minimum diameter point was used as an index of head size. Consecutive, previously caged heads were measured within the area of the field to be used for the test, and the average "minimum diameter" calculated. Heads that fell within a narrow range not far removed from the average minimum diameter were measured with calipers, tagged and infested with larvae. Stem diameters within the range of .425 to .475-inch for the first test and .450 to .525-inch for the second were used. The tests were set up as a randomized block design. Each block consisted of 5 caged heads infested with 0, 2, 4, 8, or 16 larvae each. Eighteen replications were used in the first experiment and 15 in the second. Because of the time required to measure and tag heads, and to infest with third instar larvae, 3 to 5 replications were set up and infested daily. The caged heads were observed regularly after infestation to determine if there were any adverse effects due to caging,

and if insects other than the ones introduced into the cages were present.

When the plants were mature, the heads were removed from the field with the cage in place and brought to the insectary. Here they were carefully examined to determine the number of larvae that completed development, as indicated by the presence of pupae. In cases where mortality occurred at some stage prior to pupation, the instar in which the larva died was determined by the size of the head capsule. The infestation rate was adjusted accordingly, and the rate of consumption was corrected by using the relative amount of sorghum eaten by each instar, as determined by the larval consumption test. Each head was then threshed individually, using an Amanco head thresher, and the weights recorded. The data were analyzed as linear regression, according to the procedure described by Snedecor (1959).

## Results

Caging sorghum heads as they emerged from the sheath failed to prevent varying degrees of natural infestation. Consequently, the predetermined infestation categories did not represent the true infestation. Examination of the caged heads at harvest indicated that, in many cases, there was no correlation between the numbers of corn earworm larvae introduced into the cages and the numbers present. The data were analyzed as linear regression according to the procedure used by Snedecor (1959) in

which the dependent factor, yield or ( $\bar{Y}$ ) was compared to the independent factor, insect population or ( $X$ ).

Mortality that occurred prior to the fourth instar was not detectable because the small head capsules could not be found easily. Factors of .17 and .34 were assigned to larvae that died in the fourth and fifth instars, respectively, as this represents the total percentage of grain consumed at completion of the corresponding instar according to the relative consumption test.

The results of the regression analysis for the first test are given in figure 4. The data were analyzed according to the assumption of the linear regression model  $Y = a + Bx + \epsilon$ . That is, for each selected independent value ( $X$ ) there was a normal distribution of  $Y$  from which one or more samples were taken; the means ( $\mu$ ) of all the sampled populations lie on a straight regression line, and all were normally distributed and had a common  $\sigma$ .

Test #1. The regression line, ( $A, B, C, D, E$ ) for the first test slopes downward at 3.914 units ( $b$ ) per unit of yield. As insect populations increased one larva, the yield decreased 3.914 grams. The "t" test for these data was significant at the .01 level. The mean yields ( $\mu$ ) at population points, 0, 4, 8, 12 and 16 larvae per head are indicated by points,  $A, B, C, D$ , and  $E$ . The .05 interval estimates for the respective points are indicated by the lower case figures in figure 4.

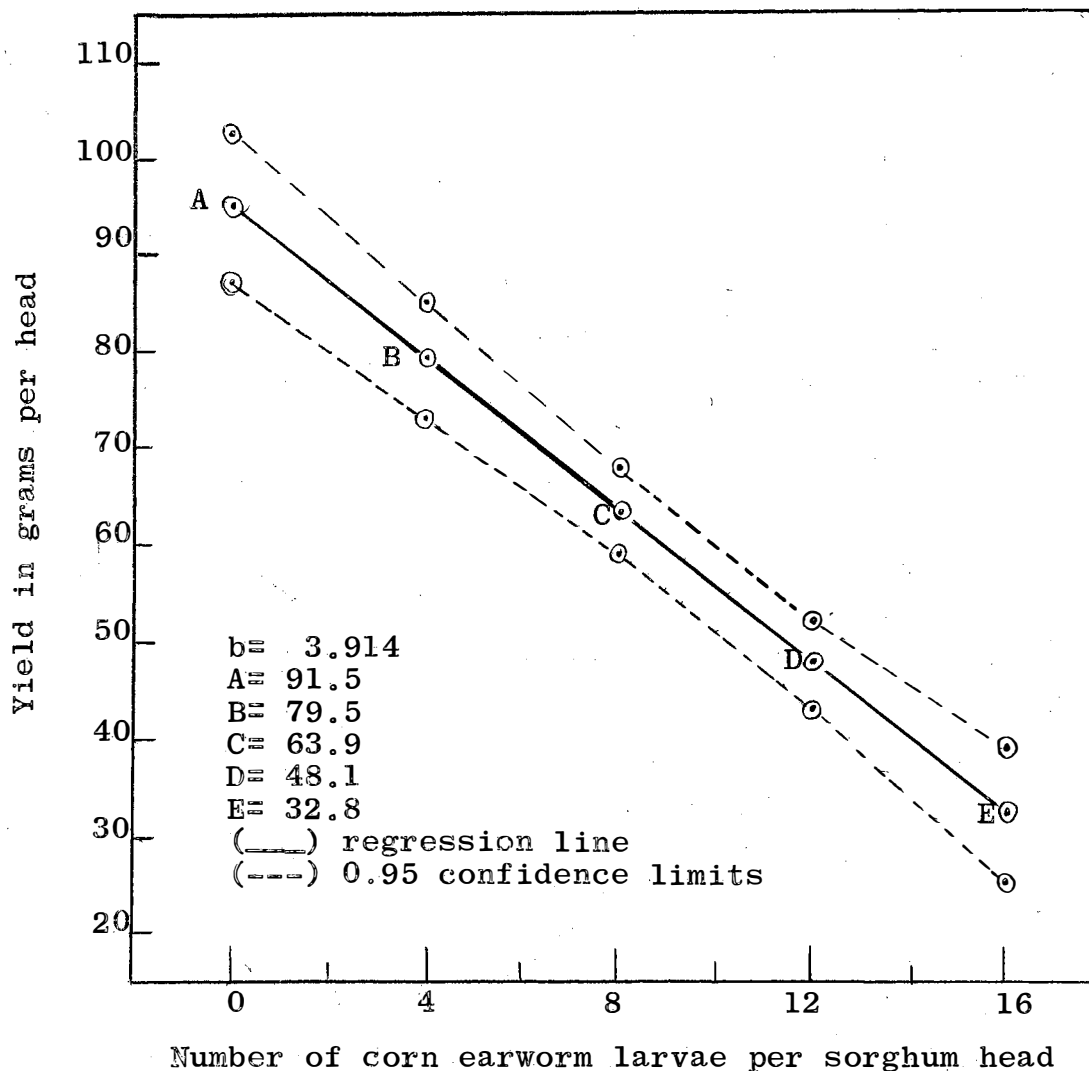


Figure 4. Regression analysis for the corn earworm yield test (Test 1) conducted on the Agronomy Farm, Stillwater, Oklahoma, Summer, 1961.

Test #2. The data for the second corn earworm control test were analyzed in the same manner as the preceding test and the results are given in figure 5. The decrease in yield, as estimated by the beta coefficient, was 3.891 grams per larva. The mean yields at infestation levels of 0, 4, 8, 12 and 16 larvae per head are indicated by points

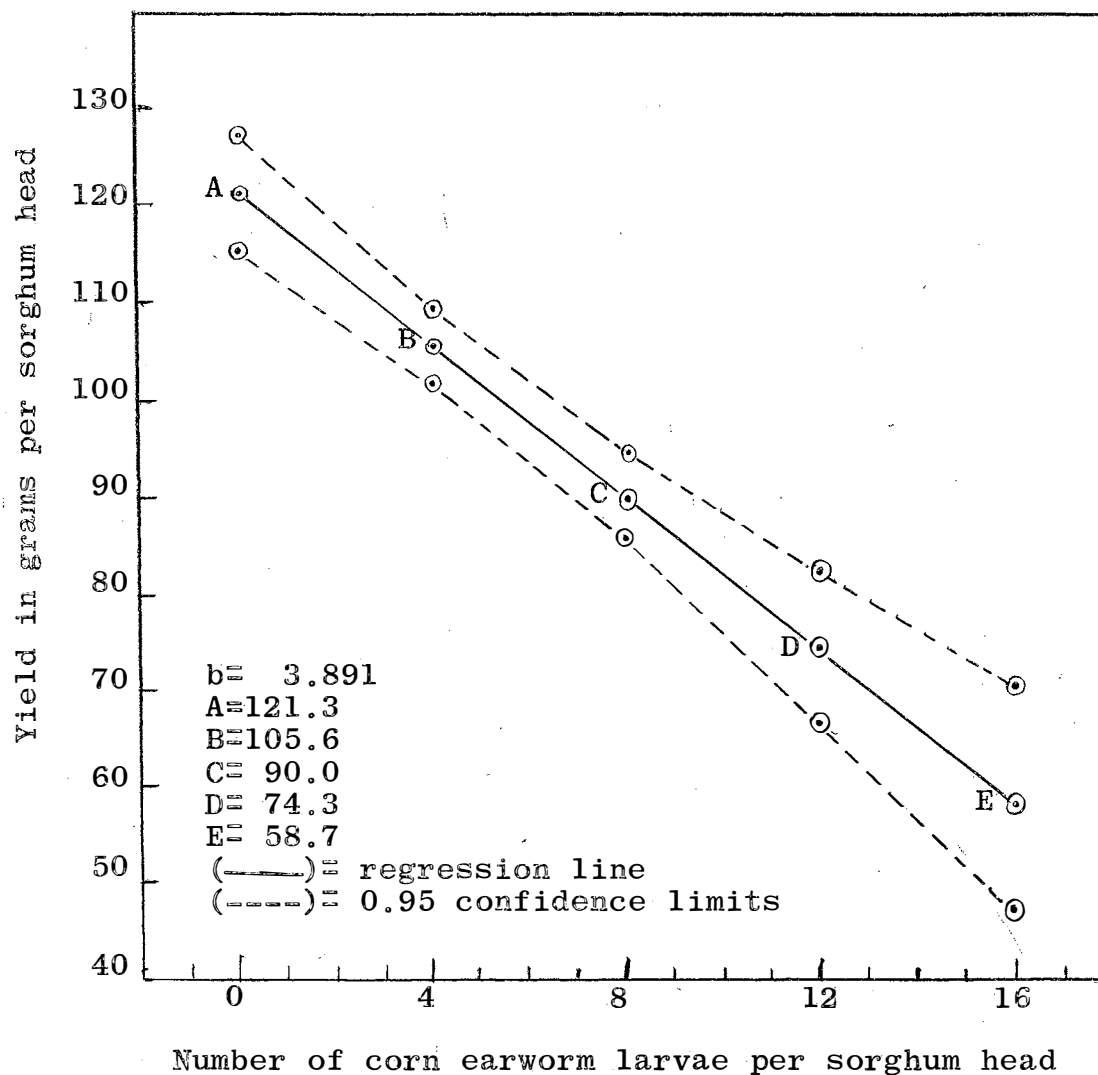


Figure 5. Regression analysis for the corn earworm yield test (Test 2) conducted on the Agronomy Farm, Stillwater, Oklahoma, Summer, 1961.

A, B, C, D, and E. Projection of the regression line would indicate that complete loss would have occurred at a population of approximately 30 larvae per head, although high population levels such as this were not used in the test.



## Discussion

Corn earworm larvae infesting corn exhibit a very high degree of cannibalism. According to Philips (1931), cannibalism is the most important factor limiting earworm populations on corn, i.e., when two larvae come in contact with each other they often fight until one or both are injured beyond recovery. Field observations indicated that this was not necessarily true in the case of corn earworm infestations in sorghum heads. Results of a preliminary test in which medium-sized sorghum heads were caged and infested with varying numbers of corn earworms indicated that as many as 13 larvae per head were able to complete the larval stage with very little cannibalism. It was observed that some cannibalism did occur as the larvae attempted to leave the head just prior to pupation and were congregating at the bottom of the cage.

To provide adequate food and space for even higher populations, and to minimize the experimental variation among the heads, plants to be used in these tests were thinned to regular intervals while they were small. The spacings used (8 and 12 inches for the two tests, respectively) were greater than the recommended spacing of 6 inches between plants. The 30x30-mesh "lumite" plastic used in making the cages for this test probably reduced air flow, and, consequently, raised the humidity within the cage a small amount. However, careful observation of the caged populations failed to detect

any adverse effect on either the plant or the larvae.

One of the more difficult problems in an experiment of this nature is that of regulating the degree of natural infestation. According to Quinby and Gains (1942), it is almost impossible to prevent earworm oviposition on sorghum heads by sacking the heads after they emerge from the boot. On the other hand, early sacking reduces predator populations.

Similar results were noted in these experiments. Although the heads were caged as soon as one-fourth to one-half of the developing head emerged from the boot (usually within 24 hours after first emergence) a moderate number of naturally occurring larvae were found in the caged heads, in addition to the ones introduced. Although the possibility exists that the eggs were deposited through the screen after the heads were caged, this is doubtful because of the fineness of the mesh. More likely, the eggs were deposited on the head immediately after emergence from the boot. Predation was not a problem in the caged heads, but reduced populations on uncaged heads tremendously.

The regression lines for Test #1 and Test #2 are compared in figure 6. Uninfested heads of the second test were 21.6% heavier than the first test. This was a result of thinning the plants to 12 inches in Test #2 as compared with 8 inches in Test #1, as well as more favorable growing conditions for the later planted field.

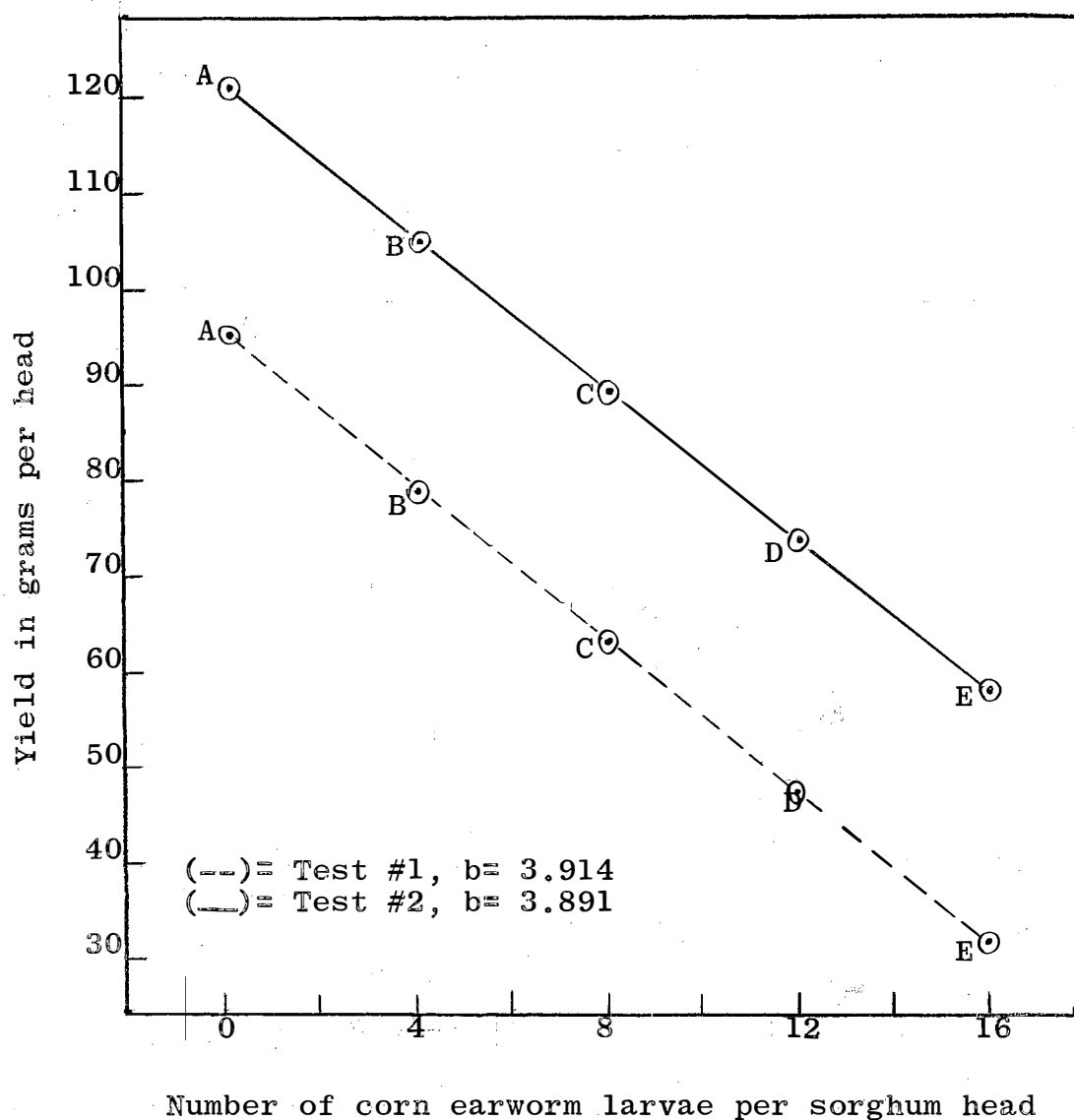


Figure 6. Comparison of the regression analyses for the two corn earworm yield tests conducted during the summer of 1961, Agronomy Farm, Stillwater, Oklahoma.

The mean yields of uninfested "check" plants were 95.1 and 121.3 grams per head for the two fields, respectively. When the total infestation was considered, the mean number of larvae per head for the first test,

characterized by the smaller heads, was 9.1 larvae. The mean number of larvae per head for the second test was 4.9. It is thus apparent that the smaller heads of Test #1 had a higher mean infestation level than the larger heads of Test #2. It is of interest that, although a higher infestation density was present in the first test, the decrease in yield per larva (as estimated by *b*) was almost identical in the two tests, and the regression lines were practically parallel. The similarity of yield reduction between the two fields differing in head size and population density, as well as the relatively narrow confidence limits (Figures 4 and 5) probably indicate that there was very little adverse effect to the larvae in cages containing very high populations.

Calculation of potential losses due to corn earworm infestations of different character were computed, using an average of the regression coefficients for the two tests. That is, on the basis of a reduction in yield of 3.9 grams per larva, the possible loss was calculated for a variety of field characteristics and infestation levels. The results are illustrated in table 3.

The row spacing selected for these calculations was 40 inches, which is standard throughout this area. The potential loss in pounds of grain per acre are given for average head spacings of 4, 8, 12 and 16 inches, and for average infestations of 0.1, 0.5, 1.0, 2, 4, 8, and

Table 3. Maximum potential losses to 40-inch row sorghum by various infestation levels of corn earworm larvae for a number of plant spacings.

Head Spacing	No. Heads Per Acre	No. Larvae Per Head	Loss (in grams) Per Head	Loss (in pounds) Per Acre
4"	39,203	0.1	.39	34
"	"	0.5	1.95	169
"	"	1.0	3.90	337
"	"	2.0	7.80	674
"	"	4.0	15.60	1,348
"	"	8.0	31.20	2,697
"	"	12.0	48.80	4,045
6"	26,136	0.1	.39	23
"	"	0.5	1.95	112
"	"	1.0	3.90	225
"	"	2.0	7.80	450
"	"	4.0	15.60	899
"	"	8.0	31.20	1,798
"	"	12.0	48.80	2,697
"	"	16.0	62.40	3,595
8"	19,602	0.1	.39	17
"	"	0.5	1.95	84
"	"	1.0	3.90	169
"	"	2.0	7.80	337
"	"	4.0	15.60	674
"	"	8.0	31.20	1,348
"	"	12.0	48.80	2,022
"	"	16.0	62.40	2,697
12"	13,068	0.1	.39	11
"	"	0.5	1.95	56
"	"	1.0	3.90	112
"	"	2.0	7.80	225
"	"	4.0	15.60	449
"	"	8.0	31.20	899
"	"	12.0	48.80	1,348
"	"	16.0	62.40	1,798
16"	9,801	0.1	.39	8
"	"	0.5	1.95	42
"	"	1.0	3.90	84
"	"	2.0	7.80	169
"	"	4.0	15.60	337
"	"	8.0	31.20	674
"	"	12.0	48.80	1,011
"	"	16.0	62.40	1,348

16 larvae per head. After determining the average head spacing and the average infestation of corn earworm larvae, the potential loss may be found in the last column.

However, other factors must be considered in making control recommendations. Three and nine-tenths of a gram of sorghum per larva probably represents the maximum grain consumption. Under unfavorable environmental conditions, such as unusually cool weather or extremely high populations that result in competition for food, and possibly cannibalism, the per-larva consumption could be less. These loss figures also assume completion of the larval stage. In the case of pre-pupal mortality, the loss would be smaller. This is an important consideration. On two occasions an unexplained disappearance of heavy populations of fourth and fifth instar larvae have been observed. The presence of large predator populations in the early stages of larval development may affect control recommendations. This is rare under field conditions. The average size of the larvae is also an important consideration, as poor chemical control often results when the majority are of the fifth and sixth instars. The potential loss figures in table 3 will provide a basis for reasonable control recommendations when the above mentioned factors are considered.

As the yield loss per head represents a maximum

amount of feeding, some statements may be made regarding populations that would definitely not be economical to control. Assuming the price of sorghum to be \$1.80 per hundred weight and the cost of treatment \$2.50 per acre, the prevention of a yield loss of 139 pounds of sorghum per acre would just pay for the treatment. Therefore, according to the last column in table 3, populations of less than 0.4, 0.6, 0.8, 1.3 and 1.7 larvae per head for average head spacings of 4, 6, 8, 12 and 16 inches, respectively, would not justify treatment. In determining the head spacings and larval populations, consecutive plants for 10 feet of row should be used as a unit. Sucker heads should not be counted as they are rarely infested and contribute little to the overall yield in most instances.

### Conclusions

Artificial infestation of caged heads was used to measure the effect of differential population densities on the yield of sorghum. The 30x30-mesh plastic "lumite" screen cage caused no noticeable adverse effect on either the corn earworm larvae or the plant. Only a small percentage of larval mortality was observed. Two similar tests were conducted in separate fields. Although average weight for uninfested heads as well as mean infestation rates were considerably different for the two tests, the yield reduction on a per-larva basis was almost the same. Reductions due to one larva as estimated

by the beta coefficient were 3.891 and 3.914 grams per head for the two tests, respectively. A table is included for making control recommendations for a variety of infestation levels and field characteristics.



## TESTS WITH THE SORGHUM WEBWORM

### Celama sorghiella (Riley)

The sorghum webworm is not an economic pest on grain sorghum in Oklahoma during most years. However, in years of higher than normal precipitation, this insect may be a serious pest, especially in the eastern part of the state, and on late-planted sorghum in the central area, as well.

#### Methods

During the late summer of 1959, infestations of the sorghum webworm were common in the eastern half of Oklahoma. One heavily infested field of RS-610 sorghum located near Drumright, Oklahoma, was used as a test field to determine the effects of sorghum webworm populations on yield. The larvae infesting this field were in the early stages of development.

Population levels were regulated by the application of a highly volatile insecticide, Phosdrin, at dosage levels of 0.75, 0.25, 0.125, 0.063 and 0.031 pound per acre. Check plots were untreated. One day after insecticidal application, 10 of 20 previously selected and tagged heads were removed from the plant, sealed in

paper bags and returned to the insectary where the populations of living larvae were determined. The remaining 10 heads per plot were allowed to mature, were threshed individually, and the weights recorded. Observations were made at intervals to determine the existence of any adverse effects to the surviving larvae attributable to insecticidal application. Seven replications were used for this experiment, and the data were analyzed as linear regression, comparing yield with the insect population.

### Results

Application of various levels of Phosdrin resulted in the establishment of differential population levels of the sorghum webworm (Table 4).

Table 4. Populations of sorghum webworm and sorghum yields remaining after application of varying dosages of Phosdrin. Drumright, Oklahoma, 1959.

Pounds Phosdrin Per Acre	Average Population Per Head	Average Yield (Grams Per Head)
Untreated	198.0	.9
0.031	48.5	17.3
0.063	35.2	30.2
0.125	16.6	40.2
0.250	9.9	54.2
0.750	2.4	52.0

Careful observations made after insecticidal application failed to detect any adverse effect to the larvae not

killed within the first few hours.

The average populations for the seven replications of each insecticidal application level and the average yields for each infestation category are shown in table 4.

The data were analyzed as linear regression comparing the dependent factor (yield) to the independent factor (insect population). The analyses were made by using the same procedure as that described on page 24 for the corn earworm data.

The analysis indicated that yield was decreased 0.68 gram per larva. Point estimates of yield at populations of 0, 20, 40 and 60 larvae per head, indicated by A, B, C, and D on the regression line (figure 7) were 54.1, 40.5, 26.9, and 13.3 grams per head, respectively.

Confidence limits for the points were: A, 49.85 to 54.09 grams; B, 37.0 to 40.49 grams; C, 22.29 to 31.51 grams; and D, 5.85 to 20.75 grams.

### Discussion

Several techniques were employed to secure differential populations of the sorghum webworm. The only method that proved satisfactory was application at various levels of a rapidly dissipating insecticide, Phosdrin.

Although careful observation failed to detect any adverse influence on the surviving larvae after insecticidal application, additional studies would have to be conducted to be certain of the absence of some chemical effect. It

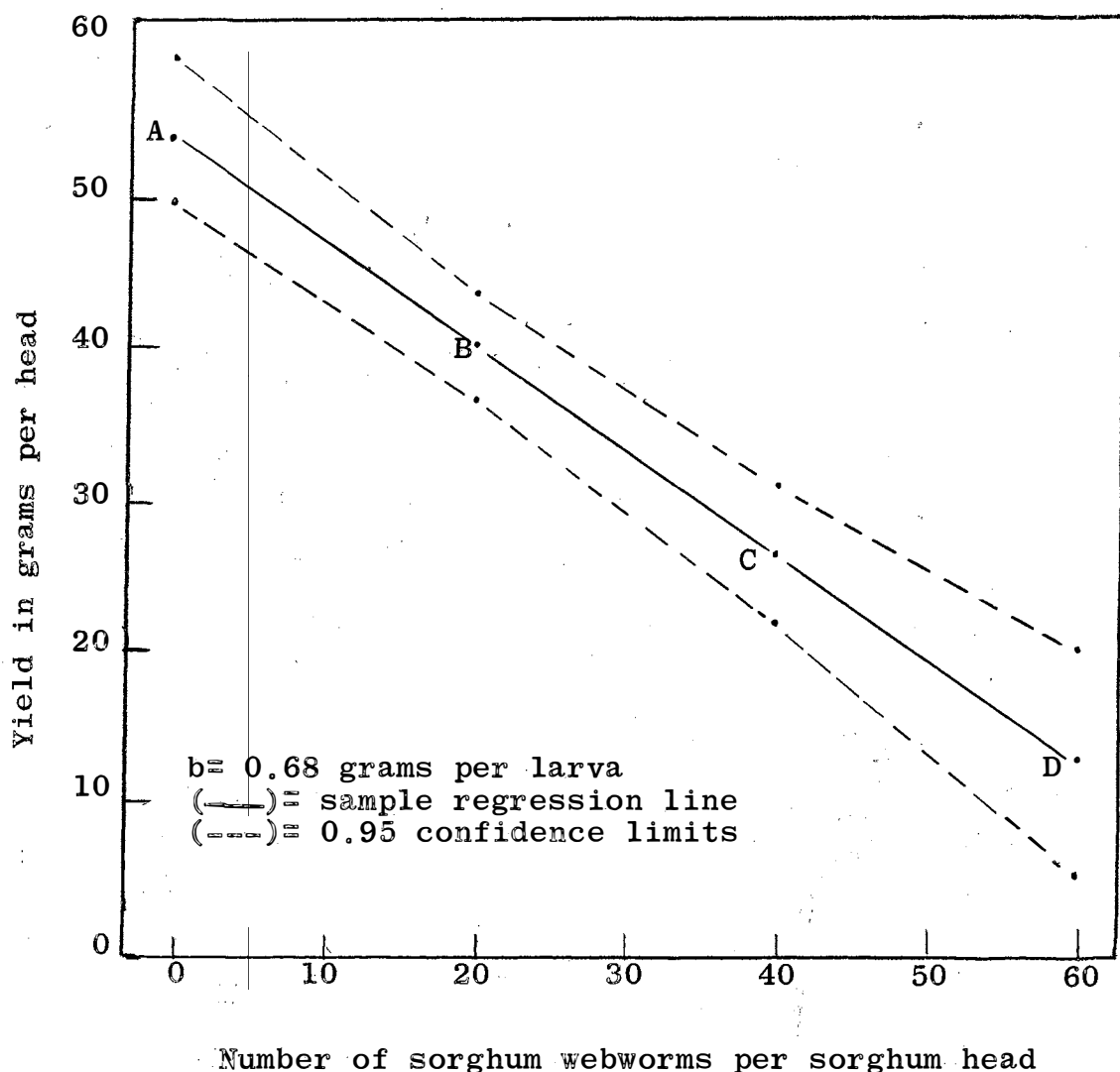


Figure 7. Regression analysis for sorghum webworm yield test conducted near Drumright, Oklahoma, during the summer of 1959.

is the opinion of the author, that, in case such a factor existed in this test, it was so slight that the effect was negligible.

The reduction in yield with the population levels attained as a result of chemical application, decreased as the dosage increased (figure 7). In the check plot, however, the heads did not furnish adequate food for the

population (198 larvae per head) and complete damage occurred before the larval development was completed.

For this reason, the control plots were not considered in the regression analysis. Using the  $b$  coefficient, 0.68, (an estimate in grams of the damage caused by one sorghum webworm larva) a table was constructed to illustrate the damage caused by population levels of 0, 5, 10, 20, and 40 webworm larvae per head under a variety of field conditions (table 5). This table was constructed in the same manner and under the same assumptions as that in the corn earworm tests (table 3).

From these data, estimations of the economic feasibility of control can be made. Populations of sorghum webworms once established, unlike corn earworms, are apparently not so vulnerable to predators or environmental conditions; consequently, the potential damage can be more precisely estimated. It is felt that the loss figures shown in the table can be followed for making control recommendations under most conditions.

Assuming a market price of \$1.80 per hundred weight for sorghum and a treatment cost of \$2.50 per acre, populations below 1.25, 2.5, 3.7, 5.7, 7.4 and 9.3 larvae per head for head spacings of 2, 4, 6, 8, 12 and 16 inches, respectively, would be uneconomical to treat.

Table 5. Potential loss to 42-inch row sorghum by various infestation levels of sorghum webworm larvae for several plant spacings.

Head Spacing	No. Heads Per Acre	No. Larvae Per Head	Loss (in grams) Per Head	Loss (in pounds) Per Acre
2"	74,670	1	.68	111.9
"	"	2	1.36	223.9
"	"	5	3.40	559.7
"	"	10	6.80	1,119.4
"	"	15	10.20	1,679.1
"	"	20	13.60	2,238.8
4"	37,335	1	.68	56.0
"	"	2	1.36	111.9
"	"	5	3.40	279.8
"	"	10	6.80	559.7
"	"	15	10.20	839.5
"	"	20	13.60	1,119.4
"	"	40	27.20	2,238.8
6"	24,890	1	.68	37.3
"	"	2	1.36	74.6
"	"	5	3.40	186.6
"	"	10	6.80	373.1
"	"	15	10.20	559.7
"	"	20	13.60	746.3
"	"	40	27.20	1,470.5
"	"	60	40.80	2,238.8
8"	18,667	1	.68	27.0
"	"	2	1.36	55.0
"	"	5	3.40	139.9
"	"	10	6.80	279.8
"	"	15	10.20	419.8
"	"	20	13.60	559.7
"	"	40	27.20	1,119.4
"	"	60	40.80	1,679.0
12"	12,445	1	.68	18.7
"	"	2	1.36	37.3
"	"	5	3.40	93.3
"	"	10	6.80	186.5
"	"	15	10.20	279.8
"	"	20	13.60	373.1
"	"	40	27.20	746.3
"	"	60	40.80	1,119.4
16"	9,334	1	.68	14.0
"	"	2	1.36	28.0
"	"	5	3.40	70.0
"	"	10	6.80	140.0
"	"	15	10.20	209.9
"	"	20	13.60	279.9
"	"	40	27.20	559.7
"	"	60	40.80	839.6

## TESTS WITH THE SOUTHWESTERN CORN BORER

(Zeadiatraea grandiosella (Dyar))

The southwestern corn borer entered the United States from Mexico around 1913. Its range has constantly increased until at present this insect is one of the most serious problems of corn growers throughout the southwestern part of the United States. According to Rolston (1950), the corn borer can survive on a number of hosts other than corn, one of which is sorghum, but on this host the larval size is smaller and the developmental period longer. Although this corn borer is not infrequently found in sorghum, it is generally not considered as a serious pest of this crop. Walton and Bieberdorf (1948) even mentioned the possibility of side-stepping southwestern corn borer damage by growing sorghum instead of corn.

During the 1961 season, corn was heavily infested by the southwestern corn borer in certain areas throughout the state. Consequently, tests were conducted to determine whether or not infestations of this pest had any appreciable effect on yield of sorghum.

### Methods

In order to measure the effect of southwestern corn

borer infestations on sorghum yields, larvae were reared to the second instar in the laboratory. Five consecutive plants in a row were tagged and infested with 5 larvae per plant. The next 5 plants in the row were not infested and served as controls. This procedure was replicated 10 times. The plants were infested in the late-whorl stage. Larvae were placed on a growing portion of the plant in the whorl region with a camel's-hair brush. At maturity, all plants were dissected to determine whether or not larvae were present, the position and extent of tunnels, and the location of the larvae in the plant. Observations were also made to ascertain if the larvae were immaculate, dead, or alive. The heads were threshed individually and the yields compared.

## Results

Eighty-two per cent of the plants infested with 5 southwestern corn borer larvae each exhibited injury at harvest. Apparently, about 20% of the plants were infested naturally as indicated by the percentage of infestation in the control plants. Plant dissection at harvest revealed that the tunneling followed a uniform pattern. The larvae entered the stalk just below the head and tunneled downward for a short distance, invariably leaving the stalk near the flag leaf. They re-entered the stalk 6 to 8 inches below the flag leaf and made a continuous tunnel to the bottom of



the crown below ground level. Girdling occurred in only 27% of the infested plants. The average head weight of uninfested plants was 78.84 grams, as compared with 67.48 grams for infested but not lodged plants and 60.9 grams for infested and lodged plants. This represents a yield reduction of 14.4% and 17.9%, respectively, for the two infestation categories. The data were analyzed according to the procedure described by Snedecor (1959) for samples of unequal size. Calculations of the "f" value indicated that there was a statistically significant difference between treatments at the .01 level.

### Discussion

Southwestern corn borer infestations of sorghum were exceptionally heavy during the 1961 season. The reason for this heavy infestation is not thoroughly understood. Gifford (1961) showed that the percentage of borers which successfully overwintered was about the same on sorghum as on corn, but attributed the usual low infestation rates in sorghum to the lack of attractiveness of this host to the ovipositing moths. However, one field kept under close observation near Stillwater showed an approximate infestation of 20%. This field was located between 2 cornfields, both of which were divided into several planting dates and were in all stages of development. One possible explanation for the unusually high infestation rate in sorghum is that the increased acreage of sorghum planted over the last few years has made it

possible for the borer to become better adapted to this host.

Although these data indicate that the southwestern corn borer is capable of causing economically significant damage, infestations are difficult to detect before considerable plant injury has occurred. One of the first signs present in the field is a small hole about 3/16-inch in diameter located a few inches below the head. At this stage of infestation, the larva is protected inside the plant and is practically impossible to control by chemical means.

The yield loss of 17.9% in plants that were infested and lodged does not represent the true loss when the crop was harvested mechanically. Lodged plants are usually bent over or lying on the ground and are seldom picked up by conventional harvesting equipment. These plants, therefore, represent a total loss to the producer.

Due to the difficulty of detecting and controlling southwestern corn borer infestations, and the low percentage of plants attacked under normal conditions, control practices will probably remain impractical until an effective systemic insecticide is developed or some practical control agent is discovered for this pest.

## TESTS WITH THE FALL ARMYWORM

### Laphygma frugiperda (J. E. Smith)

Simulated hail injury tests conducted by Davies (1962) failed to show any significant reduction in yield of grain sorghum when 40% of the total leaf area was reduced by mechanical methods. Fall armyworm feeding in sorghum whorls may result in a comparable reduction of functional leaf area.

#### Methods

An experiment was conducted during the summer of 1960 to determine whether sorghum plants compensate for fall armyworm leaf damage as they apparently do for similar mechanical injury, or if damage from this insect results in yield reduction. A field of RS-610 sorghum located near Cushing, Oklahoma, was used for this test. A moderately heavy fall armyworm infestation was present in the whorls. Thirty, six-row plots, 30 yards in length, were staked. The second and fifth rows in each plot were designated as treatment rows. The two treatments for each block (infested and noninfested) were assigned to the rows at random. All the visibly infested plants (up to a maximum of 30) were tagged in the "infested" row. A like number of plants of similar size and development

were tagged in the alternate row; however, these plants were uninfested. Plants of the uninfested rows were kept free of insects by two applications of endrin granules applied at the rate of 0.5 pound per acre. At maturity the heads were removed and threshed. The average weights of the tagged heads in the infested and uninfested rows were compared. The data for this test were analyzed as a paired experiment, comparing the average weights of infested and uninfested heads of each of the 30 replications. The procedure for this analysis has been described by Snedecor (1959).

### Results

The average yield for infested heads (24.50 grams) was only slightly lower than for uninfested heads (25.87 grams). This represents a yield loss of 5.29% due to armyworm infestation. When the data were analyzed statistically, however, there was no significant difference between treatments.

### Discussion

As there was no statistical difference between treatments in this test, statements regarding the effect of fall armyworm infestation on yield must be made cautiously. The data seem to indicate, however, that this pest does cause a detectable yield reduction when all the plants are infested. All the plants in a sorghum field in this area are seldom infested under natural

conditions. Except in cases of extremely heavy infestation (more than 25% of plants infested), this insect is of only slight economic importance when infesting sorghum whorls.

## TESTS WITH THE CORN LEAF APHID

### Rhopalosiphum maidis (Fitch)

The corn leaf aphid has long been regarded as a pest of sorghum. As early as 1921, McCollock called attention to the damage caused by this insect. He reported that this aphid ruined the sorghum crop in western Kansas in 1919, attacking both the succulent leaves of the whorl stage and the developing head as it emerged from the boot. The damage was severe, resulting in grain so shriveled that much of it failed to germinate.

### Methods

During the summer of 1961, tests were conducted to determine if head infestation of this pest resulted in yield loss.

A large number of heads were covered with "lumite" plastic screen cages (described on page 21) as they began to emerge from the boot in an attempt to prevent natural infestation by sorghum insects. When emergence was completed, 40 caged heads of similar size and development were selected. These were tagged and randomized into 10 replications of 5 treatments each, the treatments consisting of 0, 10, 50 and 500 aphids per head. Aphids

used to infest the caged heads were secured in an adjacent field of whorl-stage sorghum by removing the tender inner whorl leaves with the aphids intact. Infestation of the caged heads was accomplished by inserting these small leaves containing varying numbers of aphids in the sorghum head until the proper total number was reached. The plants were infested just prior to darkness in order to provide an adjustment period for the transition from the humid whorls to the relatively dry immature heads before temperatures increased the following day. At harvest, the numbers of aphids per head were estimated and the infestation levels compared with the respective head weights.

### Results

The majority of the heads at maturity were either heavily infested or infestation was completely lacking. A few heads had intermediate populations. There was no correlation between original infestation rate and the number of aphids present at maturity, except that the uninfested heads remained aphid free.

The heads were grouped according to aphid populations into four categories: no infestation; light infestation (0-1000); medium infestation (1,000-5,000); and heavy infestation (over 5,000). The average yield of uninfested heads was 76.1 grams. Average yields for the light-, medium- and heavily-infested categories were 79.4, 55.6 and 55.3 grams per head, respectively. This

represents a net loss in yield of 20.5 and 20.7 grams of grain per head for the medium- and heavily-infested heads, or 26.9 and 26.1% reduction in yield. No loss was shown at the light-infestation level. An analysis of variance for these data was computed according to the procedure described by Snedecor (1959). The "f" value was significant at the 0.01 probability level.

### Discussion

Head infestations of the corn leaf aphid are rare in major portions of the sorghum-growing areas of the United States, occurring only in periods of wet, humid weather. In wetter areas, such as the eastern portions of Oklahoma and Kansas, head infestations are not uncommon. Poor establishment of aphids in the caged heads used for this test was probably due to the hot, dry weather prevalent at the time of infestation. The populations of aphids indicated above as represented by the infestation levels of light, medium, and heavy are merely estimates. Counts were impossible, as most of the aphids were dead at harvest and could not be separated from cast skins and honeydew. Heads designated as heavily infested were blackened and the inner branches were caked with cast skins and honeydew. Heads designated as lightly infested had a small amount of cast skins located in the center branches. They exhibited very little blackening of the outer kerpels. Medium infested heads were intermediate between the above classifications.



Due to the relatively small number of observations and the variation between aphid populations representing each of the infestation categories, no statement could be made regarding the effect of specific population levels on sorghum yield. It can be stated, however, that heavy populations of corn leaf aphids infesting sorghum heads can result in serious yield reductions, probably even greater than the 20% shown in this test.

Considering the damage that these aphids can cause and the ease with which they may be controlled chemically, fields which have a high percentage of infested plants shortly after the heads emerge from the boot should be treated. The extent of loss will vary, however, probably being less in sorghum varieties with open-type heads and in regions of low rainfall and humidity.

## KERNEL REDUCTION BY MECHANICAL MEANS

It has long been recognized that certain plants possess the ability to compensate for a reduction in total fruit number. This results from an increase in the size of the remaining fruit. It has been stated by some entomologists that light infestations of the sorghum midge can be compensated for in this manner. An experiment was conducted during the summer of 1961 at Stillwater, Oklahoma, to determine if the sorghum plant is able to compensate for a reduction in number of fruit, and if so, to what extent it is able to compensate without yield reduction.

### Method

A field of RS-610 sorghum was used for this test. When the plants were 4 to 6-inches in height, they were thinned to approximately 8 inches. All secondary "sucker" shoots were kept from developing by periodic removal. After 90% of the heads had emerged from the boot, 120 similar-sized heads that measured .450 to .475 inch at a point  $1\frac{1}{2}$ -inches below the base of the head, were tagged according to the method described in the section on corn earworm (page 23). These plants were randomized into 20 replications of 6 treatments each. One head from

each replication was removed and the spikelets counted immediately in order to estimate the average number of kernels per head for the field. With this as a guide, the kernels in the remaining heads of each replication were reduced by approximately 0, 5, 10, 20 and 40%. Removal was accomplished by cutting off entire branches at random over the head until the desired number of spikelets had been removed. This reduction method was used to insure a range of reductions at random locations throughout the test area. Observations were made at frequent intervals in the test plots to detect and prevent injury by insects. As the grain reached the soft-dough stage, the heads were covered with plastic screen cages to prevent injury by birds.

At maturity, the heads were threshed individually and the weights recorded. In order to make an accurate estimate of the percentage of kernel reduction for each head, the following procedure was employed: Three 6.5 ml. aliquots were taken at random from each threshed head, and the average weight and number of kernels for each aliquot were computed. To determine the total number of kernels in each test (X) the following equation was used.

$$\frac{\text{Avg. wt. of aliquot}}{\text{Total head wt.}} = \frac{\text{Avg. no. kernels per aliquot}}{X}$$

By subtracting the number of kernels in each reduced head from the average number for the control heads (no reduction), the percentage of reduction was computed with a fair degree of accuracy.

### Results

A wide range of kernel reduction was accomplished by the method described above. Only a few heads had a kernel reduction of more than 40%. As the percentages of kernel reduction for this test were uniformly distributed over a wide range, rather than falling into definite reduction categories, the percentages of reduction were arranged in descending order. These were then divided into groups of 10 each, and the results are given in table 6.

A comparison of the average yield with the corresponding kernel reduction category indicates that very little decrease in yield was associated with kernel reductions of up to approximately 35%. The average yield of 74.9 grams per head for the 12.1% reduction category is a divergent figure in this regard. Apparently, the sorghum plant is unable to compensate completely for a kernel reduction of more than approximately 35%.

As the per cent kernel reduction was increased from 35.6 to 49.9% (a 27.6% increase) yield was correspondingly decreased 25.4%, further indicating that approximately 35% reduction represents the maximum level of plant compensation. Additional evidence that plant

Table 6. The effect on sorghum yield of mechanical removal of varying amounts of sorghum head parts at flowering, resulting in reductions of kernel number.

Average Per Cent Kernel Reduction	Number of Observations	Range of Per Cent Reduction	Average Kernel Weight In Mg.	Average Yield Per Head (grams)
0.0 (check)	15	- -	24.27	89.08
3.78	10	0.1- 7.1	25.86	92.10
9.6	10	7.3-12.7	26.82	89.9
12.11	10	12.8-19.0	23.76	74.9
25.4	10	22.7-28.4	32.46	88.79
35.63	10	31.5-41.2	39.61	92.23
49.90	5	43.3-53.2	37.10	68.82

compensation is terminated at approximately 35% reduction is indicated by the lack of increase in kernel size between reductions of 35.6 and 49.9%.

Seed weight increased with a reduction in kernel numbers varying from an average of 24.3 mg. per kernel in the check plots to 37.1 mg. in heads reduced an average of 49.9%. The "b" coefficient computed for these data indicates that kernel weight was increased .377 mg. for each per cent of kernel reduction.

### Discussion

The average weight of 74.9 grams per head for a kernel reduction of 12.11% is not consistent with the rest of the data. Both this figure and the average

kernel weight for this classification (23.76 mg.) are apparently lower than for groups above and below. Three observations within this group were abnormally low. An examination of the plot lay-out indicated that these observations were located in close proximity to the portion of the test area in which a number of plants were affected with "charcoal rot." Although all visibly affected plants were omitted from the test, it is possible that the 3 low observations, although affected, were either overlooked or failed to show signs of infection. Apparently, the plants are able to compensate for kernel reduction by using the nutriment normally destined for the lost kernels to produce larger remaining kernels.

Green (1962), upon failing to show a yield increase by chemical control tests for light infestations of the sorghum midge, set up a test to measure the actual loss due to removal of different amounts of head parts. He found it necessary to remove up to 15% in rather mature heads before a decrease in yield could be recorded. Results of this experiment are in agreement with Green's work in that a small reduction of total kernel number does not result in a measurable yield reduction. However, the percentage of kernel reduction necessary to cause yield reduction (approximately 35%) was much higher in this test. The difference between the two tests may be accounted for by the difference in stage of maturity of the head at the time that the reductions were made.

TESTS WITH THE SORGHUM MIDGE  
(Contarinia sorghicola (Coq.))

Methods

Studies on the effect of sorghum midge infestations on sorghum yield were conducted during 1961 at the Agronomy Farm, Stillwater, Oklahoma. A series of adjacent plots planted at 10-day intervals throughout the growing season provided ideal conditions for population build-up. As the regulation of midge population levels is impracticable on a large-scale basis, natural populations were used in this study. The adults were allowed to oviposit and the heads caged to prevent infestation by other insects. A series of heads caged immediately after emergence from the boot and before oviposition occurred served as checks. At harvest, the number of kernels destroyed by the midge was estimated by comparing the number remaining on the infested heads with the average number on the uninfested heads. The same procedure as that described on page 54 of the kernel reduction study was used for estimating the number of kernels per head.

Two methods were used to obtain differential populations of the midge. By the first method (Test No. 1),

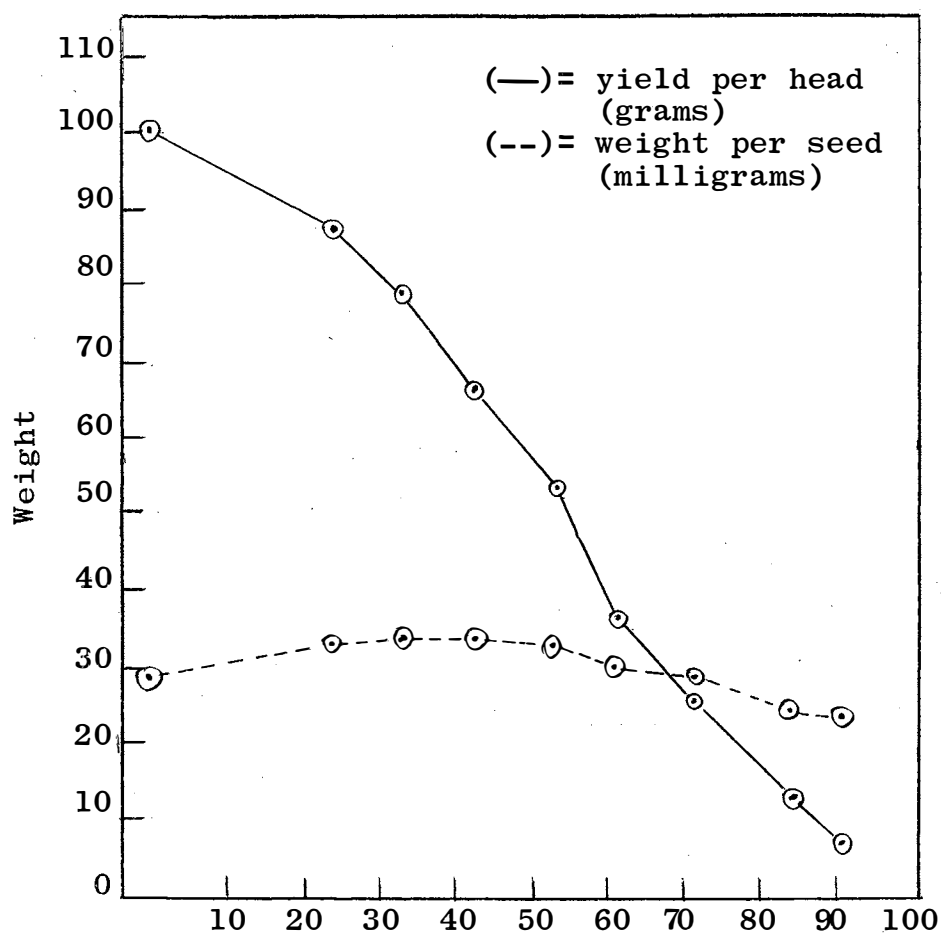
all but the check heads were left uncaged until 3 or 4 days after flowering so that oviposition could occur naturally. By the second method (Test No. 2) a number of heads was tagged in the field and randomized into 9 replications of 6 treatments each. The treatments consisted of caging the heads at various stages of flowering. One series was caged before flowering began and served as a control. Other categories were caged after the heads had completed 25, 50, 75 and 100% flowering. One series was caged 24 hours after completion of flowering. As flowering occurs early in the morning, the heads were caged late in the afternoon so that maximum oviposition could be accomplished for each category. Prior to caging, the heads were treated with smoke to insure that none of the adults remained to oviposit in the florets destined to flower the following day. The heads used for both tests were selected for size by measuring the stem at a point  $1\frac{1}{2}$ -inch below the base. Only heads with a stem diameter of between 0.475 and 0.525-inch at this point were used.

### Results

Test #1. A wide, uniformly distributed range of 25 to 90% in kernel reduction was produced by the midge infestation. Comparatively few observations were available for kernel reductions of between 0-25 and 90-100%. The observations for the first test were grouped into categories of



different kernel reductions. The average reduction, kernel weight and yield per head are given for categories of 20 to 100% at 10% intervals (Figure 8).



Per cent Kernel reduction caused by midge infestation

Figure 8. Comparison of yield and kernel weight to the levels of midge infestation (Test 1). Stillwater, Oklahoma, 1961.

Yields decreased in proportion to the number of kernels affected by the midge. However, the average seed weight changed only slightly with increased midge

attack and kernel reduction.

Test #2. As the number of observations was smaller than in the previous test, both yield and seed weight were compared with kernel reduction by regression analysis.

The results are illustrated in Figure 9.

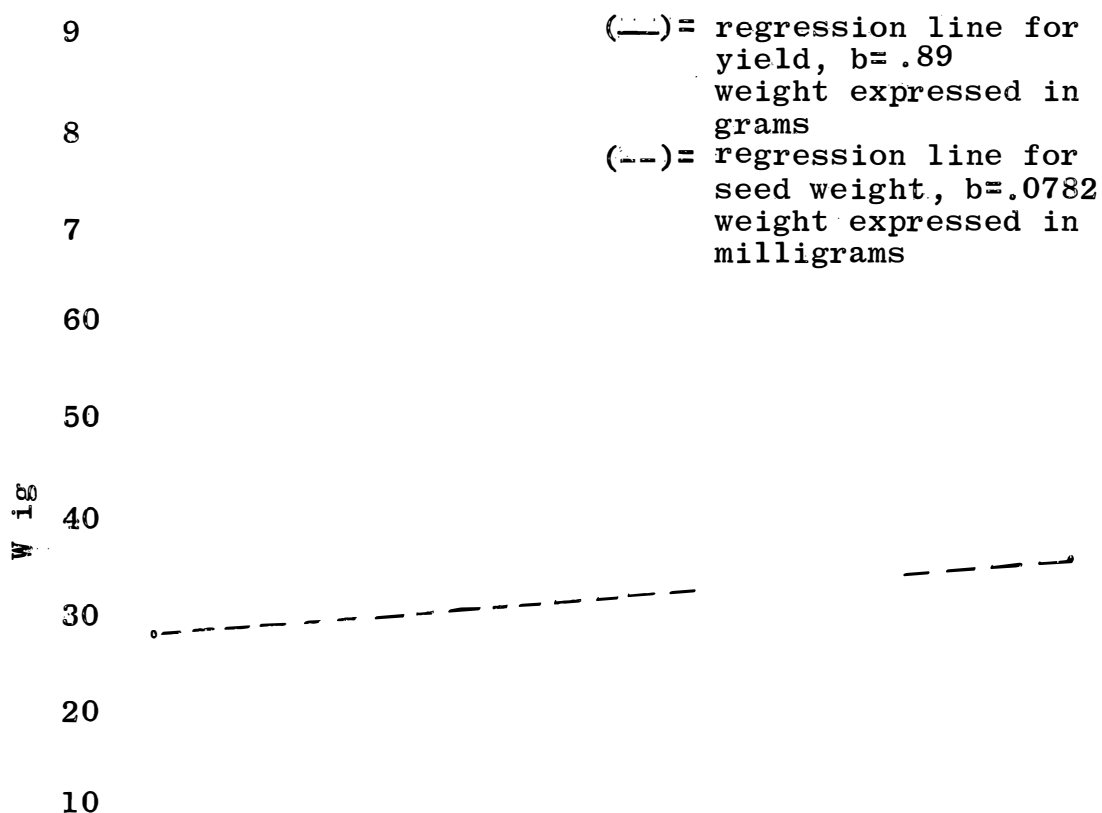


Figure 9. Comparison of regression analysis for sorghum head and seed weight subsequent to midge attack (Test 2). Stillwater, Oklahoma, 1962.

## Discussion

The sorghum midge is a minute insect with an adult life span of seldom more than 2 days. These two characteristics make population regulation of this pest by artificial means impractical. According to Walter (1953) "an infestation of one larva per spikelet is sufficient to cause the loss of the grain." Therefore, the difference between the number of kernels present at harvest for the infested heads and the average number for the uninfested checks was used as an index of infestation.

Green (1962) suggests that seed loss from light infestations of sorghum insects, including the sorghum midge, may be compensated for by the production of larger seeds. However, these data suggest that yield is decreased almost in direct relationship to the degree of sorghum midge infestation. This is further evidenced by the failure of seed weight to increase appreciably as yield decreased when both tests were considered. It is of interest that yield is decreased by light infestation of the sorghum midge, but the sorghum plant is able to compensate for mechanical reduction of up to 35% in total kernel numbers (kernel reduction test page 55).

Possibly, the way in which the kernels were removed from the heads accounts for the plant compensation. That is to say that removal of the entire branches, by mechanical means, may eliminate the necessity of maintaining flowering

parts as well as developing the embryos, allowing nutrients to be re-routed and used for the production of larger remaining seeds. When kernel reduction is accomplished by midge larvae, the nutriment otherwise destined for the production of a normal embryo is probably consumed as it enters the floret.

### Conclusions

These data suggest that sorghum yield is decreased almost in direct relation to the degree of infestation, and that the sorghum plant apparently is unable to compensate for midge infestation.

## GENERAL SUMMARY AND CONCLUSIONS

Artificial infestation of caged sorghum heads with various levels of third instar corn earworm (Heliothis zea (Boddie)) larvae was used to determine the effects of population levels of this insect on sorghum yield. Caging techniques employed failed to cause any observable effect to either the plant or the larvae. A small degree of cannibalism was noted in cages with populations of over ten larvae per head. Results from two separate tests indicated that yield may be decreased approximately 3.9 grams per head for each larva completing development.

Six application rates of a highly volatile insecticide, Phosdrin<sup>R</sup>, were used to secure differential population levels of the sorghum webworm (Celama sorghiella (Riley)). Population levels determined by field counts 48 hours after application were compared with yield at harvest. Results indicated that yield was decreased approximately 0.68 gram per head by each larva that completed development.

Yield comparisons for sorghum plants infested with the fall armyworm (Laphygma frugiperda (J. E. Smith)) indicated that reductions of approximately 5% may result from whorl infestations of this insect. As only a small

percentage of plants are infested under natural conditions in this area, and considering the slight damage they cause, chemical control is probably impractical unless over 25% of the plants are infested.

Yield reduction due to in vivo infestations of the southwestern cornborer (Diatraea grandiosella (Dyar)) were 14.4 and 17.9% for infested, not lodged and lodged plants, respectively. Because of the difficulty of detecting and controlling this pest within the sorghum plant, control practices will probably be uneconomical until more adequate means are devised.

A comparison of yield for uninfested heads and heads artificially infested with the corn leaf aphid (Rhopalosiphum maidis (Fitch)) indicated that yield was decreased 26.1% by heavy infestation. In cases where a high percentage of newly emerged heads are infested, control practices should be considered.

A reduction in total kernel number by mechanical removal of entire branches at random over the sorghum head failed to result in a comparable yield reduction. The plant was able to compensate for kernel reduction of up to 35% by the production of larger remaining seeds. For tests in which the kernel number was reduced by infestations of the sorghum midge (Contarinia sorghicola (Coq.)) however, yield was decreased in almost direct relationship to the degree of infestation. It is believed that lack of compensation in this

case was due to assimilation of the plant nutriments by the midge larvae as they became available.

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