REDUCTION OF YIELD COMPONENTS AND GREENBUG ECONOMIC THRESHOLDS IN A RESISTANT AND A SUSCEPTIBLE VARIETY OF WHEAT

By

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CHAPTER I

INTRODUCTION

Economic thresholds play an important role in integrated pest management (IPM) programs. An economic threshold is the density of a pest population at which control measures should be utilized to prevent economic damage. Resistant varieties are also an important component in IPM programs because plant resistance offers a constant, cumulative reduction in pest numbers with little or no extra cost to the producer. Moreover, the use of a resistant variety can conserve natural enemies of pest insects, preserve environmental quality, and slow the rate at which pesticide resistant strains develop (Adkisson and Dyck 1980).

The greenbug, *Schizaphis graminum* (Rondani), is a very destructive pest of small grains and sorghum in the United States. Damaging outbreaks of this pest occur frequently; therefore, growers often need to control the greenbug with insecticides. A knowledge of greenbug economic thresholds is needed to make accurate decisions as to when control measures for this pest are necessary. Economic thresholds have been studied with cereal aphids in barley (Ba-Angood and Stewart 1980), but a comparison of yield reductions and economic thresholds of resistant and susceptible wheat varieties has not been done.

The purpose of this research was: (1) to develop greenbug economic thresholds for a resistant and a susceptible wheat variety for both fall and spring field infestations based on grain yield reduction and other factors; (2) to determine in the greenhouse how a greenbug infestation affects plant growth responses such as foliage length and root weight, which in turn also affects yield responses.

CHAPTER II

LITERATURE REVIEW

The greenbug, Schizaphis graminum (Rondani), has been a damaging pest of small grains throughout the U.S. Midwest since 1890 (Starks and Merkle 1977). Damage occurs almost every year but some years are considered outbreak years and the damage then is very heavy and widespread. Up to 1972 there was at least 16 of these major outbreaks (Rogers et al. 1972). A recent outbreak occurred in 1976. During this outbreak the Oklahoma Agricultural Extension Service estimated the damage and control of the greenbug and other insect pests cost Oklahoma wheat producers 80 million dollars (Starks and Merkle 1977).

Greenbug Biotypes

Today there are five known biotypes of the greenbug in the great plains. These have been designated as A, B, C, D, and E. Biotype A predominated until the early 1960's. Biotype B, found by Wood (1961) in greenhouse cultures, became the dominant biotype in the field by 1965. Biotype B was not morphologically different from biotype A as both biotypes were dark green in color with black-tipped cornicles. However, biotypes A and B can be separated by the reaction of 'Dickinson Selection 28-A' (DS-28A) and CI 9058 wheats; both were resistant to biotype A but were susceptible to biotype B. The two biotypes also differed in their method of feeding. Biotype A inserted the stylets intercellularly and fed in the phloem tissue (Saxena and Chada 1971); whereas, biotype B inserted the stylets both intra and intercellularly and fed in the mesophyll parenchyma of the leaf (Wood et al. 1969).

Biotype C was discovered during the summer of 1968 when very large populations of greenbugs caused extensive damage to sorghum on the High Plains of Oklahoma and Texas (Harvey and Hackerott 1969). Biotype C was also very destructive to small grains and after 1968 it replaced biotype B as the dominant biotype in many areas. Biotype C had greater fecundity at extreme temperatures than biotypes A and B (Wood and Starks 1972). Perhaps this enabled biotype C to attack small grains in the winter and sorghum during the summer. Like biotype A, biotype C feeds in the phloem tissue (Wood 1971a). Biotypes B and C could be separated by their reaction to 'Piper Sudangrass' (Harvey and Hackerott 1969).

Biotype D was first reported by Teetes et al. (1975). Compared to the other biotypes, biotype D had a high level of resistance to organophosphorous insecticides (Peters et al. 1975). Biotype D is morphologically identical to biotype C and probably gave the same plant reaction as biotype C, but this was not confirmed (Starks and Burton 1977a).

Biotype E was first reported in Bushland, TX by Dr. K. B. Porter, Texas A and M University during the winter of 1979-80. Results of plant reactions with Biotype E (unpublished USDA-ARS report, 1980) are as follows: 'Amigo', a wheat variety which was resistant to all previous biotypes of the greenbug, is now susceptible to biotype E. 'Gaucho' triticale from which 'Amigo' was derived, shows a mixed reaction (ca. 25% of plants resistant). 'Will' barley has lost a considerable amount of tolerance; and previously resistant oats still have resistance to biotype E. Biotype E also appears to have overcome much of the resistance in commercial sorghum varieties.

Greenbug Reproduction

Greenbugs normally found in the field are alate or apterous females which produce their young parthenogenetically and ovoviviparously. The greenbug normally undergoes five instars from birth to maturity; however, paedogenesis has been demonstrated to occur in greenbug populations (Wood and Starks 1975). Parthenogenesis, ovoviviparity, and paedogenesis all contribute to the greenbug's high fecundity rate. Twenty-five generations of ovoviviparous greenbugs can occur annually in Oklahoma.

The optimum temperatures for greenbug reproduction are 20.9° to $23.9^{\circ}C$ (Wood and Starks 1972). Under these conditions adult greenbugs can produce as many as ten nymphs/day.

A few sexual forms of this aphid do occur in the field and the greenhouse but greenbug eggs resulting from the mating of sexual forms have not been demonstrated to be viable in the U.S. (Mayo and Starks 1972).

Greenbug Damage

In Oklahoma, the greenbug does much of its damage early in the spring. Due to rapid population increases greenbug infestations may remain undetected until large yellow or brown spots (greenbug spots) appear in the wheat field. Greenbugs kill or damage plants by: (1) injecting toxic secretions while feeding; (2) removal of plant sap; and (3) transmission of viral diseases. The toxin can cause plasmolysis of cells, which become disorganized and the nucleus can swell out of proportion. In extreme cases, the cytoplasm disintegrates and ultimately the cell wall ruptures (Saxena 1969). The removal of plant sap is normally the least damaging of these mechanisms because a very large number of aphids is required to remove enough plant sap to cause significant damage to plants (Wood 1971b). Greenbugs transmit barley yellow dwarf virus and maize dwarf mosaic virus (Starks and Burton 1977a). This can be a concern for varieties resistant to aphids because aphids can transmit the disease merely by probing the plant with their stylets (Maramorosch 1980). Therefore, sustained feeding as would occur on susceptible varieties may not be needed.

Saxena (1969) explained that a resistant plant may be one that is able to tolerate the greenbug toxin. A resistant plant may accomplish this by three mechanisms: (1) producing chemicals that neutralize the toxin; (2) developing anatomical structures that keep the secretion localized; and (3) eliminating the toxin by some physiological process at a later stage.

Externally, the damage the toxin produces is first evident by the dark necrotic spots which appear over the leaf surfaces. At this stage the damage is important because it can reduce the rate of photosynthesis. With more extensive damage the leaves yellow and die. In addition, greenbug infestations can severely retard root development so that a heavily infested plant will not recover and yield like an uninfested plant (Daniels 1965).

Economic Thresholds

To prevent greenbugs from causing extensive damage in wheat, current control recommendations emphasize that the cost of control should be less than the total value of the crop loss if no chemical controls were utilized (Ba-Angood and Stewart 1980). This economic approach involves the timing of control methods based on the pest density, the size of the plants, the amount of damage to the plants, and the potential control by beneficial insects or other environmental factors. To describe such relationships Stern et al. (1959) developed the concepts of economic thresholds and economic injury levels. The economic threshold is the density at which control measures should be utilized to prevent a pest population from reaching the economic injury level. The economic injury level is that point where the potential loss due to a pest species exceeds the cost of control.

Greenbug economic threshold research in wheat, includes the field study of Dahms and Wood (1957), in which they found the least greenbug damage occurred when control measures were used early in plant growth. They also found that an infestation of 100 greenbugs/ft caused a reduction from 2.1-4.6 pounds of grain/acre/day. In greenhouse studies, Ortman and Painter (1960) found that the maximum percent root weight loss for four varieties averaged 46% and the maximum percent leaf weight reduction, compared with the uninfested controls ranged from 14-65%. Daniels (1965) found in the greenhouse that greenbugs indirectly caused more damage to the roots of wheat plants than to the aerial portions of the plant. He reported an average of 73% reduction in root weight and 60% reduction in foliage weight in five varieties of winter wheat. Apablaza and Robinson (1967) infested spring wheat in the field at 6, 16, 26, 36, 46, 56, and 66 days after germination with one apterous adult greenbug/plant. In this study, they found that the maximum days to kill wheat plants ranged from 20-35 days depending on the age of the plants infested. Recommendations from the Texas Agricultural Extension Service (1979) state that chemical controls should be applied on wheat plants three to six inches high, when 100-300 greenbugs/ft-row exist. Likewise, plants four to eight inches and six to sixteen inches high should be treated when greenbugs respectively reach the levels of 200-400 and 300-800/ ft-row. Kieckhefer and Kantock (1980) found that losses in spring wheat were the greatest when the greenbug S. graminum and the oat aphid Rhopalosiphum padi (Linnaeus) fed on wheat in the seedling stage. Population densities as low as 25-30 aphids/stem in seedling stage significantly reduced the yield. Densities of 30-40 aphids/stem during the boot stage also caused reductions in most yield components ($P<0.01$).

In barley, Ba-Angood and Stewart (1980) when working with the oat aphid, R. padi and the English grain aphid, Sitobion avenae (Fabricius) found infestation levels of 40, 80, 160, and 200 aphids/tiller reduced grain yields significantly. The aphids were allowed to feed on caged barley plants in the field at the flowering and milky stages for two weeks. They found economic injury and economic threshold levels in southwestern Quebec to be 10-18 and 8-16 aphids/tiller, respectively, depending on the rate of increase of the aphids, the costs of chemical control, and the monetary value of the crop.

Plant Resistance

Plant resistance can be valuable in limiting damaging infestations of greenbugs. The resistance is specific for the pest species and does not have a devastating effect on beneficial insects. Moreover, complete immunity to an insect species is unnecessary because the effect of the resistance on the pest population can be compounded in successive generations. Plant resistance is also advantageous in that there are no adverse side effects on the environment (Metcalf and Luckman 1975).

Painter (1951) divided plant resistance to insects into three mechanisms: antibiosis, nonpreference (antixenosis), and tolerance. A combination of these mechanisms may interact to produce insect resistance in a given variety. Gallun (1972) reported that resistance to insects and the ability of an insect to utilize a plant are both genetically controlled. According to Allard (1960), an insect reaction involves an interaction of genes conditioning resistance in the host with those conditioning virulence in the insect.

Greenbug Resistance and Mode of Inheritance in Small Grains

In wheat, resistance to biotype A of the greenbug was found by Dahms et al. (1955). One of the resistant selections was 'Dickinson Selection 28-A' (DS 28-A), which was then used in breeding programs in Kansas, Oklahoma, and Texas. Painter and Peters (1956) found that the greenbug resistance in 'DS 28-A' was controlled by a single recessive gene. This result was later confirmed by Daniels and Porter (1958). Later, 'DS 28-A' was found to be susceptible to biotype B and, even later, to C. The USDA world wheat collection was then screened for resistance to biotype C but a high level of resistance was not found. The plant breeders thus turned to related genera. 'Insave F.A.' rye had a high level of resistance to the greenbug, due to a single dominant gene. This rye was crossed to 'Chinese Spring' wheat, resulting in the triticale 'Gaucho' (CI 15323). From these crosses, Sebesta and Wood (1977) developed and released 'Amigo' (CI 17609), a hard red winter wheat germ plasm which was resistant to greenbug biotypes A, B, and C.

With the recent appearance of biotype E, the resistance in 'Amigo' now has been overcome. However, about 25% of the'Insave F.A.' rye plants maintained at Stillwater, OK, are resistant to biotype E and might be exploited. Another source of resistance to be exploited is that found in *Triticum tauschii* (coss.), a species of goat grass. *T. tauschii* has been crossed to Langdom durum resulting in a germ plasm line called 'Largo'. 'Largo' was developed at Fargo, North Dakota, and is resistant to greenbug biotypes C and E (Dr. Owen G. Merkle, personal communication, USDA, ARS, Stillwater, OK).

CHAPTER III

MATERIALS AND METHODS

Field Study

Location and Experimental Design

The field utilized for the 1979-80 study, located at the Agronomy Research Station near Perkins, Oklahoma, was 109.73 m (360 ft) long by 24.38 m (80 ft) wide. The experiment was arranged in a split plot design. The main plots were varieties and the sub plots consisted of a level * season factorial. One factor was season of infestation (fall or spring) and the other factor was level of infestation. The main plots were in a randomized block design with five replications. Each replicate was divided into entries of resistant and susceptible lines of wheat. The resistant entry (variety) was Tam -W 101/Amigo (OK 78014), while the susceptible variety was Tam -W 101. The resistant variety was available for this study because it was a less promising line and, therefore, was not taken for seed increase. The order of the entries was randomized in each replicate and the field was planted with a 22.86 cm (9 in) drill planter on 15 October 1979.

The 1980-81 study was located on the USDA farm (Stillwater, OK). The field was 91.44 m (300 ft) long by 27.43 m (90 ft) wide. The same experimental design and varieties was utilized as the 1979-80 study.

The fall 1980 planting was done with a 17.78 cm (7 in) drill planter on 2 October 1980.

Each entry in each replicate had ten 0.30 m-row (1 ft-row) experimental units (plots). These experimental units were randomized throughout the entry according to the order in which they would be infested and the level of infestation to which they were to be designated. This process was carried out separately for both fall and spring tests. In the fall, plots were to have peak infestation levels 0, 10, 20, 40, and 60 greenbugs/plant. In the spring because of larger plant size, the levels were increased to 0, 20, 40, 60, and 80 greenbugs/plant. Before the plots were infested in the fall, the wheat was thinned to five plants/0.30 m-row (1 ft-row). The same process was repeated in the spring with ten different plots.

Eight of the experimental units (2 plots for each level) were infested with approximately five biotype C greenbugs/plant. The greenbugs were allowed to increase until the infestation reached the designated levels. Then the plots were treated with disulfoton to prevent further greenbug infestations. It sometimes became necessary to place additional aphids in plots designated for high infestation levels (40-80 greenbugs/plant) so that the greenbugs would reach the designated levels (See Table I). Once a plot was treated with disulfoton, it was monitored throughout the season to make sure it was free of greenbugs. Since the fall and spring infestations were conducted separately, it was sometimes necessary to re-treat the fall plots with disulfoton in the spring to prevent further greenbug infestations.

The remaining two experimental units were retained as undamaged plots by treatment with disulfoton to determine maximum yield without greenbug infestation. Extra experimental units were added (except for the fall 1979 test where there was only 1 plot/level) to insure there were sufficient units for each level.

Greenbug Rearing

Greenbug cultures were reared on a susceptible barley or a barley-sorghum mixture in the greenhouse. Approximately 30 seeds/pot were planted and after emergence, plants were covered with transparent plastic cages to insure that the cultures were free of extraneous insects and to confine the greenbugs. The open top of the round cage and the two ventilation holes in the sides of the cage were covered with a fine-mesh cloth. Approximately two weeks after planting, pots were infested by placing two plants containing greenbugs from previous cultures into the cages (Starks and Burton 1977a). After two weeks, populations had increased sufficiently to be used for field infestation. These infestations were performed by lightly and uniformly tapping the plants on which the greenbugs were reared over the wheat plants in the experimental plots (for infestation dates see Table I).

Data Collection

The number of greenbugs/plant and the height (cm) of each plant from the ground to its outstretched tip were recorded from each plot. The plots were also rated for damage using a one to nine scale, with one indicating no damage, while a rating of nine indicated all plants were dead or dying (See Table II for rating scheme). Experimental plots received a damage rating of one only if all plants were very healthy and vigorous. Thus, it was possible for uninfested control plots to receive a damage rating of two. These measurements were made at least once a week on all of the infested plots. The date the plots were treated with disulfoton was also recorded. Thus, it was possible to obtain the number of days, or exposure time a particular experimental plot was infested with greenbugs by calculating the number of days between initial infestation and treatment. This data made it possible to determine how long it took greenbugs to build up to a certain level on the resistant compared to the susceptible wheat varieties.

The wheat heads were harvested by hand at maturity (Table I). Heads from each plot were placed in a separate brown paper bag to prevent plot mixing. The replication number, season (fall or spring), and the plot number were recorded on each bag. For the 1980 harvest, as the wheat was cut, the number of fertile tillers was counted and recorded for each plot. Later, the heads were threshed by hand and the threshed kernels placed in separate seed packets for each plot. The seed was then cleaned, weighed on a balance accurate to 0.10 grams, and the weight of all the seed in a plot was the grain yield/plot. The number of seed/plot was then counted with a seed counter. The number of fertile tillers, grain yield, and the number of seed/plot were all converted to a per plant basis by dividing by the number of plants/plot. The 1981 harvest differed slightly in that the number of fertile tillers were counted two weeks prior to harvest, the heads were threshed on a machine thresher, and a balance accurate to 0.01 grams was utilized.

The data from each experimental plot consisted of the grain yield/ plant, the number of fertile tillers/plant, the number of seed/plant, and the damage ratings. The formulae utilized for converting grain yield in grams/plot to kilograms/hectare (kg/ha) or bushels/acre (bu/ac) were as follows:

$$kg/ha = \frac{(107{,}639.4)(gyp)}{(A)(1000)}$$

Where: 107,639.4 = sq ft/hectare. gyp = grain yield/plot. A = sq ft harvested (0.75 in 1979-80 and 0.58 in 1980-81). 1000 = gm/kg.

$$bu/ac = \frac{(43{,}560)(gyp)}{(A)(453.6)(60)}$$

Where: 43,560 = sq ft/ac. 453.6 = gm/lb. 60 = lbs wheat/bu.

Greenhouse Study

Experimental Design

The greenhouse experiment was a randomized block design with eight replications. Each replicate had five resistant (Tam -W 101/Amigo) and five susceptible (Tam -W 101) wheat plants. Three wheat seeds of the designated variety were planted in 15.2 cm (6 in) diameter pots filled uniformly to 1.25 cm (0.50 in) from the top of the pot. The pots were placed with adequate spacing (4 replicates/table) on two tables in the greenhouse. Border pots were placed around the four replicates to equalize the amount of light and air circulation each pot would receive. Before wheat plants emerged, they were caged with transparent plastic cages. A few days after emergence the wheat plants were thinned to one plant/pot. Because the wheat was planted in sand, it was watered with a complete fertilizer solution three times weekly. The infestation levels for each rep were: 0, 5, 10, 15, and 20 greenbugs/plant. Each caged plant was infested by hand at the two-leaf stage.

Data Collection

Greenbugs were allowed to feed on infested plants for ten days. At this time, the total number of greenbugs on each plant was counted. The damage rating, foliage length, foliage weight, root volume, and root weight responses were then measured. The damage rating was based on a one to nine scale which was similar to the system utilized in the field study (Table II). The length of the foliar portions was measured from the level of the top of the pot to the outstretched tip of the leaf. The foliage was then cut off at the level of the top of the pot and weighed while still fresh. The sand was removed from the roots by washing the sand out of the pot, and rinsing the roots. When the roots were air dried their volumes were determined by displacement of water in a graduated cylinder. Later, the same roots were placed in a drying oven for 72 hours at 35^{o}C. The oven dried roots were then weighed on a balance to the nearest 0.01 gram.

CHAPTER IV

RESULTS

Field Study

The data for the 1979-1980 and 1980-81 studies differed considerably. Grain yield and two of its components (number of fertile tillers/plant and number of seed/plant) were greater in 1980-81 than in 1979-80. This was probably due to a difference in locations or a difference in experimental years. When the data for the two years were combined, a significant experimental year (E yr)*Season interaction occurred. The presence of a significant E yr*Season*Variety interaction would limit the interpretation of the difference between experimental years and the difference between seasons. Therefore, each experimental year and each season have been discussed separately because of: (1) location differences from one year to the next; (2) different infestation levels in the fall than in the spring; (3) vigorous growth of plants in the spring may mean they could withstand more greenbug damage than in the fall.

Fall 1979

Grain Yield/Plant. The grain yield/plant during the fall 1979 infestation generally showed a decreasing trend as the greenbug infestation increased in both the resistant and susceptible varieties (Fig.

1). The trend leveled out somewhat between the 20 and 40 levels of infestation, but then continued to decrease. The difference between varieties can best be seen at the higher infestation levels. For example, at the 60 level of infestation, the grain yield of the resistant variety was 3.41 times greater than that of the susceptible variety. Overall, the average reduction in grain yield due to greenbug damage was 0.41 grams/plant in the resistant variety and the average reduction in grain yield for the susceptible variety was twice that at 0.81 grams/plant.

The susceptible variety initially had larger grain yields than the resistant variety at the zero and ten levels of infestation, perhaps this was due to varietal differences. Perhaps, because of this, the overall grain yield response did not show significant differences between the resistant and susceptible varieties. However, differences in grain yield due to levels of infestation were highly significant ($P = 0.0001$) when data were averaged over varieties.

Number of Fertile Tillers. The number of fertile tillers/plant generally showed a decreasing trend as the greenbug infestation was increased (Fig. 2). For both resistant and susceptible varieties, this response (similar to the grain yield response) had a leveling trend from the 20 to the 40 levels of infestation, but then the decrease in tillers continued at the higher infestation levels. The susceptible variety had more fertile tillers than the resistant variety at the zero and ten levels of infestation (probably a varietal response), while the resistant variety had more fertile tillers at the 20, 40, and 60 levels of infestation. As expected the resistant variety tolerated the higher levels of infestation much better than the susceptible variety. For example, at the 60 level, the number of fertile tillers for the resistant variety was eight times greater than that for the susceptible variety. When all levels of infestation were combined, (except 0 level) the average reduction in the number of tillers for the resistant variety was 0.36 tillers/plant, while the average reduction in the number of tillers for the susceptible variety was twice that at 0.72 tillers/plant. Probably due to the varietal differences at the low infestation levels, there were no significant differences between the resistant and susceptible varieties based on the number of fertile tillers, but differences due to levels of infestation were highly significant (P = 0.0001) when data were averaged over varieties.

Number of Seed/Plant. The number of seed/plant showed a decreasing trend as the greenbug infestation was increased (Table III). Except for the zero level, the resistant variety had a greater number of seed/plant than the susceptible variety. The greatest difference between varieties was at the 20 level of infestation, where the number of seed/plant of the resistant variety was 2.76 times that of the susceptible variety. Nevertheless, this test did not show a significant difference in the number of seed/plant due to varietal effects, but there were significant differences in seed/plant due to infestation levels (P = 0.05) when data were averaged over varieties.

Damage Rating. The damage rating for both the resistant and susceptible varieties increased as the level of greenbugs increased (Table III). Little damage difference was apparent at the ten infestation level but increased substantially from the 10 to the 20 level.

The difference then remained more or less constant as the level of infestation increased. The susceptible variety had heavy visual damage at the 40 and 60 levels of infestation. Many of the plants did not survive at these higher levels. Even the resistant variety showed heavy damage at the 60 infestation level. When data for levels were combined, there was a significant difference between the resistant and susceptible varieties (P = 0.01).

Yield Reduction. Table IV shows that when all the levels of greenbug infestation (excluding the 0 levels) were combined, the grain yield of the resistant variety was 1.42 times that of the susceptible variety. The large difference between the average yields at the zero level in the resistant and susceptible varieties as indicated before was a varietal difference. The rate at which the yields of either variety were reduced by increasing levels of greenbugs was a more typical result than the initial difference between varieties because one would expect the yields of the susceptible variety to be reduced much more than the yields of the resistant variety. For example, starting at the ten level of infestation, each addition of ten greenbugs/plant reduced the yield of the resistant variety by 174.52 kilograms/hectare (kg/ha) or 2.60 bushels/acre (bu/ac). For the susceptible variety, each addition of ten greenbugs/plant reduced the yield by 323.78 kg/ha (4.81 bu/ac).

Spring 1980

Grain Yield/Plant. The grain yield/plant for spring 1980 plots generally showed a decreasing trend as the greenbug infestation increased (Fig. 3). Varieties had similar grain yields for both the zero and 20 levels. However, at the 40, 60, and 80 levels of infestation, the grain yield of the resistant variety exceeded that of the susceptible variety (all infestation levels combined) by an average of 0.72 grams/plant. The overall grain yield/plant (0 levels not included) also demonstrated the difference between varieties; for the mean of the resistant variety was 1.76 grams/plant, while the mean of the susceptible variety was 1.17 grams/plant.

Each increase of 20 greenbugs/plant (not including 0 levels), resulted in a 0.56 gram/plant reduction in the grain yield for the resistant variety. On the other hand, each increase of 20 greenbugs/plant reduced the grain yield for the susceptible variety by 0.78 grams/plant. The grain yield response had significant differences between the resistant and susceptible varieties ($P = 0.01$) and highly significant differences due to levels of infestation ($P = 0.0001$) when data were averaged over varieties.

Number of Fertile Tillers. Increasing the level of greenbug infestation resulted in a decrease in the number of fertile tillers/plant for both the resistant and susceptible varieties (Fig. 4). The susceptible variety again had a slightly greater number of tillers/plant than the resistant variety at the zero and 20 levels of infestation. Thereafter, the number of tillers of the resistant variety exceeded those of the susceptible variety by an average of 0.62 tillers/plant. The difference between varieties was largest at the 60 and 80 levels of infestation, where the resistant variety had an average of 1.14 more tillers/plant than the susceptible variety. Each increase of 20 greenbugs/plant (excluding 0 levels), reduced the number of tillers of the resistant variety by 0.43 tillers/plant and the susceptible variety by 0.69 tillers/plant. Infestations of approximately 57 greenbugs/plant reduced the number of tillers of the resistant variety by one-half. For the susceptible variety this same reduction required approximately 37 greenbugs/plant. There were significant differences between the resistant and susceptible varieties ($P = 0.01$), and differences due to levels of infestation were highly significant ($P = 0.0001$) when the data were averaged over varieties.

Number of Seed/Plant. As for all previous responses, this response showed a decreasing trend as the greenbug infestation was increased (Table V). The resistant variety had a greater number of seed/plant than the susceptible variety at every level of infestation. The reduction in the number of seed no longer decreased for the resistant variety following the 60 level of infestation. Conversely, the reduction in the number of seed/plant continued throughout all levels in the susceptible variety. At the 80 level of greenbug infestation the number of seed/plant for the resistant variety was 6.43 times greater than that of the susceptible variety. Significant differences occurred between the resistant and susceptible varieties ($P = 0.05$) and significant differences due to levels of infestation ($P = 0.01$) also existed when data were averaged over varieties.

Damage Rating. The visual damage to wheat plants appeared more severe on both varieties as the number of greenbugs were increased (Table V). Plants of the susceptible variety showed heavy damage at the higher levels of infestation. The damage to many plants was so great that they failed to survive. The resistant variety appeared to receive heavy damage at the highest (80) level but only moderate damage at the 60 level. The difference in damage between the varieties grew progressively greater as greenbug levels were increased. There was a significant difference due to levels of infestation (P = 0.0001) when data were averaged over varieties.

Yield Reduction. Table VI shows the reduction of the yield of an infested plot as compared to the controls. Considering all levels of infestation (except the 0 level), the yield of the resistant variety was 1.50 times that of the susceptible variety. Moreover, each addition of 20 greenbugs/plant (excluding 0 level) reduced the yield of the resistant variety by an average of 400.42 kg/ha (5.95 bu/ac); whereas, each addition of 20 greenbugs/plant reduced the yield of the susceptible variety by an average of 556.38 kg/ha (8.27 bu/ac). There were significant differences between the resistant and susceptible varieties (P = 0.01) and a highly significant difference due to infestation levels (P = 0.0001).

Fall 1980

Data from the 1979-80 study differed considerably from that of the 1980-81 study. This may be due to location or difference in years. The main difference is that the 1980-81 yields were much greater than those of 1979-80. It is not understood why the yields were so high in the 1980-81 study. However, the overall yields, as such, were not the important aspect of the study; the reduction in yield due to greenbug damage was the primary concern. Actually, these differences in years or location could broaden the study by extending the research to new and different conditions.

Grain Yield/Plant. A reduction in grain yield/plant for both the resistant and susceptible varieties occurred as greenbug infestations were increased (Fig. 5). The resistant variety exceeded the susceptible variety at every level of infestation. In addition, the difference in grain yield between varieties increased as the greenbug infestation increased. For example, at the 40 level, there was a 2.98 gram/plant difference between the two varieties, while at the 60 level there was a 4.93 gram/plant difference between the two varieties. Beginning at the 20 level, each addition of 20 greenbugs/plant reduced the grain yield of the resistant variety by 3.58 grams/plant; whereas, each addition of 20 greenbugs/plant reduced the grain yield of the susceptible variety by 5.12 grams/plant. There were significant differences between the resistant and susceptible varieties ($P = 0.05$) and highly significant differences due to levels of infestation ($P = 0.0001$) when the data were averaged over varieties.

Number of Fertile Tillers. The number of fertile tillers/plant was significantly reduced ($P = 0.01$) by greenbug infestations (Fig. 6). The difference between the number of fertile tillers for the two varieties increased as the number of greenbugs increased. At infestations greater than the 20 level, each addition of 20 greenbugs/plant reduced the number of tillers of the resistant variety by 1.73 tillers/plant and the susceptible variety by 4.14 tillers/plant. As a result, there were significant differences between varieties ($P = 0.05$).

Number of Seed/Plant. The number of seed/plant of both varieties decreased as the number of greenbugs was increased (Table VII). The resistant variety produced more seed/plant than the susceptible variety at every infestation level. The resistant variety much better than the susceptible variety appeared to tolerate the higher levels of infestation. For example, at the 60 level, the number of seed for the resistant variety was 5.34 times that for the susceptible variety. The overall mean (all infestation levels combined except 0 level) of the resistant variety was 1.47 times that of the susceptible variety. There were significant differences between the resistant and susceptible varieties (P = 0.01), and differences due to infestation levels were highly significant (P = 0.0001) when the data were averaged over varieties.

Damage Rating. The visual damage to wheat plants by greenbugs showed no difference between varieties until the 40 infestation level was reached (Table VII). At this point, the differences were considerable, the resistant variety showing exceptional tolerance to the greenbug infestations. Even at the 60 level the resistant variety only showed moderate damage. Considering these plants were fall seedlings the damage appeared somewhat lighter than expected for both varieties. The damage ratings were significantly different between varieties (P = 0.01) and the difference due to infestation levels were highly significant (P = 0.0001) when the data were averaged over varieties.

Yield Reduction. The yield from the resistant variety exceeded the susceptible variety at every infestation level and as the infestation levels were increased, the difference between the resistant and susceptible varieties also increased (Table VIII). When all levels of infestation were combined (except 0 level), the yield of the resistant variety was 1.30 times that of the susceptible variety. From the infestation level of 20 greenbugs/plant, each addition of 20 greenbugs/plant reduced the yield of the resistant variety by 3,319.92 kg/ha (49.37 bu/ac) and that of the susceptible variety by 4752.05 kg/ha (70.66 bu/ac). This response had significant differences between varieties (P = 0.05) and highly significant differences due to levels of infestation (P = 0.0001) when the data were averaged over varieties.

Spring 1981

Grain Yield/Plant. A decreasing trend in grain yield/plant occurred for the resistant and susceptible varieties as the greenbug levels were increased (Fig. 7). A substantial drop in grain yield occurred at the 40 level for the susceptible variety. Therefore, at the 40, 60, and 80 levels, the grain yield of the resistant variety exceeded that of the susceptible variety (all infestation levels combined) by an average of 4.14 grams/plant. Each increase of 20 greenbugs/plant reduced the grain yield of the resistant variety by 3.29 grams/plant and the susceptible variety by 4.81 grams/plant. The overall means for grain yield (0 level excluded) demonstrated the difference between varieties because the overall mean for the resistant variety was 10.46 grams/plant, while the overall mean for the susceptible variety was 7.45 grams/plant. There were significant differences between the resistant and susceptible varieties (P = 0.01) and highly significant differences due to levels of infestation (P = 0.0001) when the data were averaged over varieties.

Number of Fertile Tillers. The number of fertile tillers/plant decreased as the greenbug infestation increased for both the resistant and susceptible varieties (Fig. 8). At all levels of infestation, except the zero level, the resistant variety had more tillers/plant than the susceptible variety. Each addition of 20 greenbugs/plant (excluding 0 level) reduced the number of tillers of the resistant variety by 2.32 tillers/plant, and the susceptible variety by 3.73 tillers/plant. The number of tillers/plant was severely reduced beginning with the 40 infestation level for the susceptible variety, but it was not until the 80 infestation level that the number of tillers/plant was severely reduced in the resistant variety. The number of fertile tillers had significant differences between the resistant and susceptible varieties (P = 0.01), and differencs due to levels of infestation were highly significant (P = 0.0001) when the data were averaged over varieties.

Number of Seed/Plant. The number of seed/plant for the resistant and susceptible varieties decreased with an increase in the greenbug numbers. Table IX shows that the resistant variety had a greater number of seed/plant at every infestation level. The resistant variety performed much better than the susceptible variety at the higher levels of infestation. As an example, at the 40, 60, and 80 levels of infestation, the number of seed of the resistant variety was twice that of the susceptible variety (all infestation levels combined). Moreover, each increase of 20 greenbugs/plant (excluding 0 level) resulted in a 92.91 seed/plant reduction for the resistant variety and a 127.87 seed/plant reduction for the susceptible variety. This response had significant differences between the resistant and susceptible varieties (P = 0.01) and highly significant differences due to levels of infestation (P = 0.0001).

Damage Rating. Visual greenbug damage to the wheat plants increased as infestation levels increased. The susceptible variety had higher damage ratings (more damage) at every infestation level (Table IX). The difference between the resistant and susceptible varieties was largest at the 40 level, where the susceptible variety had visible damage twice that of the resistant variety. At the 60 and 80 levels, damage to many susceptible plants was so great they were unable to survive. The damage rating response showed significant differences between resistant and susceptible varieties (P = 0.01) and highly significant differences due to levels of infestation (P = 0.0001).

Yield Reductions. The yield of the resistant and susceptible varieties decreased as the greenbug levels were increased (Table X). The susceptible variety out-yielded the resistant variety at the zero and 20 levels of infestation by an average of 481.19 kg/ha (7.16 bu/ac). However, the resistant variety out-yielded the susceptible variety at the 40, 60, and 80 levels of infestation by an average of 3832.94 kg/ha (56.99 bu/ac). Each increase of 20 greenbugs/plant (excluding the 0 level) reduced the yield of the resistant variety by 3037.12 kg/ha (45.16 bu/ac), while in the susceptible variety each increase of 20 greenbugs/plant reduced the yield by 4440.45 kg/ha (66.03 bu/ac).

General Linear Models

General linear models were computed separately for each experimental year (1979-80 and 1980-81). This analysis considered linear effects, effect of fall and spring seasons, and varietal effects (resistant and susceptible) on the grain yield/plant, number of fertile tillers, and the damage rating responses.

1979-1980 Study

Grain Yield/Plant. When general linear models were computed based on grains yields for the two varieties, there was an overall linear effect (P = 0.0001). This linear effect was produced by the increases in infestation levels which caused a decrease in grain yields (Fig. 1).

A comparison of seasons were made by calculating straight lines for the varieties (based on grain yields) using fall and spring data. The result was the two straight lines were parallel. This indicated that the grain yield reduction, had the same general trend in both fall and spring. Although straight lines were parallel, the quadratic and cubic effects of these same data were significantly different (P = 0.01). This indicated that the curvature of these seasonal lines was not the same.

When testing differences between varieties, the fall and spring data were averaged together. From these data, a straight line was calculated for each variety. The two straight lines were not parallel (P<0.01), indicating the resistant and susceptible varieties do not respond the same when the greenbug infestation level increased. This **was the expected result as parallel lines from zero would indicate no** difference in damage between the resistant and susceptible varieties. In this case, the curvature about the two straight lines were quite similar (P>0.10).

Number of Fertile Tillers. When general linear models were computed based on the number of fertile tillers, the same trends were seen as in the grain yield response. In this test, the only difference between these two responses was the curvature was different about the two straight lines, when the variety effects were tested.

Damage Rating. The damage rating response also followed some of the same trends as the grain yield response (1979-80 study), when the general linear models procedure was computed. The damage rating response did differ from the grain yield response, in that the test for season effects showed the fall and spring lines were not parallel.

1980-81 Study

Grain Yield/Plant. When general linear models were computed based on grain yield for the two varieties, there was an overall linear effect ($P = 0.0001$). This linear effect was produced by increases in infestation levels which caused a decrease in the grain yields (Fig. 4).

A comparison of seasons was made by calculating straight lines for the varieties (based on grain yields) by using the fall data for one line and the spring data for the other. The resulting straight lines were not parallel ($P<0.01$), and the quadratic effects about the two lines were not the same ($P<0.05$).

When testing differences between varieties, the fall and spring data were averaged together for each variety. From these data straight lines were calculated for the resistant and susceptible varieties. This test indicated that the two straight lines were not parallel ($P = 0.0001$), and curvatures about the two lines were not the same as was indicated by the quadratic and cubic effects.

Number of Fertile Tillers. When general linear models were computed based on the number of tillers, the same general trends were seen as in the 1980-81 grain yield response. In this test, the only difference between the two responses was the curvature about the fall and spring lines for the season comparison was not the same.

Damage Rating. When general linear models were computed based on damage ratings, the same general trends were seen as in the 1980-81 grain yield response. The damage rating response differed only in the curvature about the resistant and susceptible lines, when the variety effects were tested.

Greenhouse Study

The data collected in the field only measured plant response in terms of grain yield, number of fertile tillers and number of seed/plant. Heavy greenbug damage to the plants showed a considerable reduction in all of these responses. However, the data did not show why these reductions might have occurred. The greenhouse study was designed to measure growth or foliage length, foliage weight, root weight and root volume, indirect responses of the plants to greenbug damage. These responses explain how greenbug damage caused the reduction in yield components.

Damage Rating. Both the resistant and susceptible varieties showed an increase in damage as the greenbug infestation increased (Fig. 9). As expected, the damage to the susceptible variety increased much more than the resistant variety. For example, at the highest infestation level (20 greenbugs/plant), the resistant variety had a damage rating of 4.50, while the susceptible variety had this same damage rating at the 10 level of infestation. In addition, the overall damage rating mean for the resistant variety was 2.98, whereas, this mean for the susceptible variety was 4.45. The damage rating response had highly significant differences between the resistant and susceptible varieties (P = 0.0001) and highly significant differences due to infestation levels (P = 0.0001).

Growth. The growth rate (final height-initial height) showed a decreasing trend as the greenbug infestation increased (Table XI). The resistant variety had more plant growth than the susceptible variety at every level of infestation. The two varieties had very similar growth rates at the zero and five levels of infestation; however, the infestation level of 15 greenbugs/plant reduced the growth rate of the susceptible variety 1.94 times that of the resistant variety. The overall growth rate for the resistant variety (excluding 0 level) was 16.76 cm, but it was only 11.61 cm for the susceptible variety. Each increase of five greenbugs/plant (including 0 level), resulted in an average 3.31 cm reduction in the growth rate for the resistant variety and this reduction was 3.90 cm for the susceptible variety. There were significant differences between the resistant and susceptible varieties (P = 0.0001) and highly significant differences due to infestation levels (P = 0.0001). The growth response has shown that the growth of both varieties was significantly reduced by greenbug infestations and throughout the test, the growth of the resistant variety was significantly greater than the growth of the susceptible variety.

Final Greenbug Count. Table XI shows the increase in greenbug reproduction as the level of infestation increased. During the ten day test, greenbugs increased by an approximate factor of eight, on both the resistant and susceptible varieties. At every infestation level except the highest (20) level, the susceptible variety had more greenbugs than the resistant variety. The exception occurs at this level because the heavily damaged susceptible plants began to die leading to a reduction in the greenbug population. The final greenbug count did not show a significant difference between the resistant and susceptible varieties.

Foliage Weight. Foliage weight generally decreased as the greenbug infestation increased (Table XI). Although the resistant variety was taller than the susceptible variety, the foliage weight response did not show significant differences between the resistant and susceptible varieties. As a matter of fact, the overall mean of the susceptible variety was greater than the overall mean of the resistant variety. Heavy greenbug infestations may have prevented the resistant variety from producing additional leaves that are normally produced as the plant grows. In addition, the time frame for this experiment may not have been great enough to allow potential differences between varieties to appear. However, as in previous responses, there were highly significant differences due to infestation levels (P = 0.0001).

Root Volume. Root volume decreased as the greenbug infestation was increased (Fig. 10). The roots of the resistant variety seemed to withstand the higher levels of infestation much better than the susceptible variety. For example, the root volume of the resistant variety at the 15 and 20 levels, were respectively, 2.05 and 2.30 times the root volumes of the susceptible variety. Each increase of five greenbugs/ plant (excluding 0 level), resulted in an average reduction of 0.0750 ml in root volume for the resistant variety and 0.029 ml for the susceptible variety. There were highly significant differences between the resistant and susceptible varieties (P = 0.0001) and highly significant differences due to infestation levels (P = 0.0001).

Root Weight. Root weights for the resistant and susceptible varieties followed the same general trend from one infestation level to the next (Fig. 11). The resistant variety had a greater root weight than the susceptible variety at every infestation level. The root weight of the resistant variety at the 20 level, was 2.02 times the root weight of the susceptible variety. Moreover, the overall root weight mean (all infestation levels except 0 combined) for the resistant variety was 0.0328 grams, while the overall mean for the susceptible variety was 0.0240 grams. There were significant differences between the resistant and susceptible varieties (P = 0.05) and differences due to infestation levels were also significant (P = 0.05).

It is interesting that both the root weight and root volume were significantly reduced in the resistant as well as the susceptible variety. The roots of infested plants were shorter, had fewer root hairs, and had smaller adventitious roots than the controls.

Table XII demonstrated that all four responses (root weight, foliage weight, root volume, and foliage length or growth) averaged approximately the same reduction from the controls. The root weight response (both varieties combined) averaged a 68.7% reduction from the controls. In comparison, the foliage weight response averaged a 63.5% reduction from the controls. This indicated greenbug infestations affected the root systems as much as the foliage portions of the plant, and this finding agreed with Daniels (1965).

CHAPTER V

DISCUSSION

Effects of Greenbug Damage

Typically, greenbug damage is first evident by small necrotic spots which appeared over the leaf's surface. In the studies reported herein, necrosis was seldom seen in the resistant variety, but high infestation levels (60 to 80 greenbugs/plant) caused the lower leaves to yellow. The 60 and 80 levels of infestation caused severe damage to the susceptible variety, as the leaves usually turned brown and the plants sometimes died. Possibly, in the higher levels of infestation, the greenbug toxin accumulated in both varieties, altering cells and their contents. Internally the chloroplast cells can be destroyed by the toxin and ultimately the cell wall ruptures, leaving vacuolar spaces in the parenchyma (Saxena 1969).

Wheat plants may become stunted under a heavy greenbug infestation (Dahms and Wood 1957). Such stunting may be permanent and if so, the plants will probably not yield nearly as much as normal plants. The severe reduction in height (stunting) could be a result of the toxin killing the plant at the growing point, so that the plant does not continue to grow (Dr. Owen G. Merkle, personal communication, USDA-ARS, Stillwater, OK). The stunting of infested wheat may also be due to the reduction of the root system, which was shown to occur in the greenhouse study (see greenhouse section). The reduction of wheat root systems by greenbug infestations can affect the plant's survival in at least two ways: (1) it can influence the plants ability to take up water and nutrients and; (2) it could make them more susceptible to winter kill thereby lowering their yield potential (Ortman and Painter 1960).

Greenbug feeding affected wheat yields by causing kernel shrinkage and improperly filled heads (Dahms and Wood 1957). The grain yield, number of fertile tillers, and the number of seed/plant were all significantly reduced by greenbug infestations. The data from the spring 1980 grain yield, number of fertile tillers, and number of seed/plant responses showed the damage to the resistant variety appeared to level off at infestations greater than 60 greenbugs/plant. This could be a result of: (1) the ability of the resistant variety to withstand the additional greenbug damage; or (2) the greenbugs leaving the experimental plots when large populations and extensive damage have occurred.

Movement of Greenbugs

Movement of greenbugs from plant to plant within the experimental plots and at times out of the plots when high populations or severe damage had occurred, created problems in counting to establish infestation levels. Greenbugs seemed to move around more on resistant wheat plants than susceptible plants, which confirms the finding of Starks and Burton (1977b).

Calculation of Economic Thresholds

To calculate an economic threshold, the current selling price of wheat and the cost of an insecticide application are needed. The value of wheat was placed at $3.85/bu and the cost of an aerial application of parathion was approximately $4.00/ac for these studies. With these prices, any reduction in yield greater than one bu of wheat/ac (67.25 kg/ha) would constitute an economic threshold.

Fall Economic Thresholds

Tables IV and VIII indicated that for the fall 1979 and 1980 infestations a reduction of 67.25 kg/ha (1 bu/ac) occurs for both varieties at infestations between zero and ten greenbugs/plant. Therefore, if ten greenbugs/plant were considered to be the economic threshold level for these studies (10 greenbugs/plant was used as an estimate), and 18-20 plants the average number of plants/0.30 m-row (1 ft-row); the economic thresholds for the resistant and susceptible varieties in either fall infestation was 180-200 greenbugs/0.30 m-row (1 ft-row) (10 greenbugs/plant x 18-20 plants/0.30 m-row). It must be considered that plants in this test were thinned to five plants/0.30 m-row and that plants were from 5-13 cm in height.

Spring Economic Thresholds

From table VI, it is possible to approximate the economic thresholds for the spring 1980 infestation. In this season, the economic thresholds occur somewhere between 20 and 40 greenbugs/plant for the resistant variety, and the economic thresholds for the susceptible variety were between zero and 20 greenbugs/plant. This was again based on wheat selling for $3.85/bu. A graph of yield reduction vs. infestation levels gives a better approximation of where the economic thresholds were for this test. Fig. 12 shows the reduction of 67.25 kg/ha (1 bu/ac) occurred at the approximate infestation of 30 greenbugs/plant, for the resistant variety. For the susceptible variety, this same reduction occurred at approximately 12 greenbugs/plant.

The economic thresholds for the spring 1981 infestation probably occurred for the resistant variety at approximately 20 greenbugs/plant (Table X). The approximate economic thresholds for the susceptible variety occurred at infestations less than 20 greenbugs/plant. Fig. 13 indicates the yield reduction for the susceptible variety occurred at approximately five greenbugs/plant.

With this information, the number of greenbugs/unthinned 0.30 m-row (1 ft-row) causing economic damage can be calculated. If 18-20 plants are considered to be the average number of plants/0.30 m-row, the economic threshold for the resistant variety in the spring 1980 infestation would be 540-600 greenbugs/0.30 m-row (1 ft-row) (30 greenbugs/plant x 18-20 plants/0.30 m-row). The economic thresholds for the susceptible variety were much lower, 216-240 greenbugs/0.30 m-row (1 ft-row). In this test the plants were from 10-20 cm in height.

The economic threshold in the spring 1981 infestation was 360-400 greenbugs/0.30 m-row (20 greenbugs/plant x 18-20 plants/0.30 m-row) for the resistant variety and 90-100 greenbugs/0.30 m-row for the susceptible variety. The plants in this test ranged from 12-35 cm in height.

Comparing the Economic Thresholds

When comparing the economic thresholds found in this study with recommendations from the Texas Agricultural Extension Service (1979), the fall 1979 and 1980 tests had economic thresholds that agreed with the Texas recommendations. According to the Texas recommendations, plants 7.6-15.2 cm (3-6 in) in height had economic thresholds of 100-300 greenbugs/0.30 m-row (1 ft-row). The economic thresholds for this study, for plants with a similar height were 180-200 greenbugs/0.30 m-row, assuming the economic thresholds were at 10 greenbugs/plant.

In the spring 1980 test, the plants were 10-20 cm in height (ca 4-8 in). At this height, the Texas recommendations stated that control measures should be implemented when 200-400 greenbugs/0.30 m-row (1 ft-row) were present. The resistant variety had economic thresholds that exceeded the Texas recommendations (540-600 greenbugs/0.30 m-row) but the economic threshold of the susceptible variety was in the lower range of the Texas guidelines (216-240 greenbugs/0.30 m-row).

The economic thresholds for the spring 1981 tests were lower than anticipated. According to the Texas guidelines, economic thresholds for plants 15.2-40.6 cm (6-16 in) tall, which was the height of the plants in this test, should be from 300-800 greenbugs/0.30 m-row (1 ft-row). Even the resistant variety, which had economic thresholds ranging from 360-400 greenbugs/0.30 m-row, was in the lower range of the Texas guidelines. The susceptible variety ranged from 90-100 greenbugs/0.30 m-row.

It is not known under what growing conditions the Texas Agricultural Extension Service developed their guidelines; therefore, it may be difficult to compare the Texas guidelines with the economic thresholds of this study.

Lack of Rainfall

Moisture deficiency may be responsible for the economic thresholds being lower than anticipated. The fall 1979 and 1980 economic thresholds were probably a little low for both the resistant and susceptible varieties. This may be a result of the dry weather during the infestations or the small size of the plants 5-13 cm (2-5 in). Weather records at the Perkins station for the fall of 1979 showed that drought conditions occurred from August through October. The amount of rainfall received, 12.1 cm (4.8 in), was 13.8 cm (5.5 in) below the long term average for that station. In the fall of 1980 rainfall for October through November, at the Stillwater station totaled only 5.26 cm (2.1 in), which was 6.5 cm (2.6 in) below the long term average for that station (Fig. 14).

In the spring 1981 test, the low economic thresholds were unexpected because of the height of the plants (12-35 cm). It is possible the economic thresholds may have been low because of the lack of moisture received during the month of April. During this month, the Stillwater station received only 2.3 cm (0.89 in) of rain which was 5.0 cm (1.97 in) below the long term average for that station (Fig. 14).

Other Factors That Influence the Study

Weather was an important factor in the field study because a week of extremely low temperatures (below $-6^{o}C$) reduces greenbug populations (Daniels 1980). Conversely, very dry weather can cause the wheat to be moisture stressed. Moisture stress in combination with greenbug infestations may produce an additive effect so that the wheat plants might not be able to withstand as much damage as they could under adequate moisture conditions (Ortman and Painter 1960).

The parasitoid, Lysiphlebus testaceipes (Cresson), and predators like the lady beetle, Hippodamia convergens (Guerin-Meneville) attacked the greenbug in late March and early April of the spring study, and October and early November in the fall study. Fortunately, most of the spring infestations had reached their designated levels when this beneficial insect became effective, and in the fall the cool weather limited the effectiveness of the predators or parasities. L. testaceipes did a very good job of controlling greenbugs at the Perkins Station and at Stillwater, OK, but after the experiment was near completion. Resistant varieties, in combination with this parasitoid, could be very valuable to growers because they work together to reduce the number of greenbugs (Starks et al 1972).

Other Pests

Not all the damage to wheat plants in this study was restricted to greenbug feeding. Other wheat pests such as the army cutworm, Euxoa auxiliaris (Grote); a wireworm, Agriotes spp.; the chinch bug, Blissus leucopterus leucopterus (Say); the English grain aphid, S. avenae; the oat bird cherry aphid, R. padi; and the two-stripped grasshopper, Melanopus bivittatus (Say) were also found in the experimental plots. The above insects were of minor importance and except for the army cutworm, no damage could be detected by their feeding in the experimental plots. The army cutworm did "graze" off foliage from a few plants in some plots, but this damage did not appear to be important; for in almost every instance, regrowth of the foliage occurred. Moreover, loose kernel smut Ustilago tritici (Person), was found on a few wheat heads in the field but this disease was only found once in the experimental plots, Some powdery mildew, Erysiphe graminus tritici (Marchal), and some wheat leaf rust, Puccinia recondita tritici (Erickson), were also found on the foliage of the experimental plots.

Exposure Time

The number of days greenbugs were allowed to feed in the experimental plots or exposure time is shown in Table XIII. Greenbug increase rates between varieties were similar. In the 1979-80 tests, the resistant variety had slightly greater exposure means than the susceptible variety. In contrast, for the year 1980-81, the susceptible variety had greater exposure means than the resistant variety. It was anticipated that the resistant variety would have greater exposure means than the susceptible variety because the resistant variety was believed to have some antibiosis. These results may be important in that the resistant variety may not suppress greenbug generations as much as expected. In contrast, the damage ratings of the resistant variety were significantly lower than the susceptible variety in all seasons this study was conducted. The higher infestation levels of the resistant variety also needed to be infested more often than the susceptible variety. Moreover, the overall yields and economic thresholds of the resistant variety were greater than those of the susceptible variety.

The fact that a resistant variety slows the build up of pest populations is important to growers. This could mean that spraying operations could be delayed and the longer time interval in population build up may give predators and parasites a better chance to regulate the pest. The result of utilizing resistant varieties may be that it may take longer for insect populations to build up to the economic thresholds.

Differences in the amount of time greenbug infestations were allowed to persist also affects the amount of damage a plant may receive. For instance, greenbug infestations were only maintained on the lowest infestation levels (10 and 20 levels) for about two weeks; whereas, greenbug infestations were maintained at the 60 level for about four weeks because it took more time to build up to this higher level. The longer time interval may be important in inflicting more damage to the higher infestation levels.

Summary

Greenbug infestations are damaging to wheat in several ways; the grain yield, number of fertile tillers, number of seed/plant, and the root systems can all be significantly reduced by greenbug feeding and damage.

In the field study, a decreasing trend occurs in grain yield/plant and two yield **components (number of fertile tillers and number of seed/** plant) as the greenbug infestation is increased. For the damage rating response, the visual damage to wheat plants increased as the greenbug infestation increased. The susceptible variety often out-performed the resistant variety at the zero level and the lowest infestation level because of varietal differences, but in all responses, the resistant variety out-performed the susceptible variety at the higher infestation levels (40-80 greenbugs/plant). This study has shown: a heavy greenbug infestation in the fall could cause critical injury to wheat plants so that they yielded little in the spring, and a light infestation of greenbugs (10-20/plant), in either the fall or the spring, can cause a reduction in yield.

Important points to be gained from the general linear models analysis were the fall and spring lines parallel for the season tests, and the resistant and susceptible lines parallel for the variety test. In both experimental years the test for variety effects showed the resistant and susceptible lines were not parallel. The test for season effects demonstrated the fall and spring lines were usually parallel in the 1979-80 study; whereas, in the 1980-81 study, the fall and spring lines were not parallel.

In the greenhouse study, all plant growth responses (growth rate, foliage weight, root volume, and root weight) decreased with increasing levels of greenbugs. The greenhouse study has shown greenbug infestations reduce the root systems as much as the foliage portions of the plant. The reduction of root systems is important in the field because it can affect the plant's ability to perform optimally and to survive a heavy greenbug infestation.

Both the field and greenhouse studies have shown that the resistant variety tolerated the higher levels of greenbug infestation better than the susceptible variety; therefore, the resistant variety would be the better choice when greenbug infestations occur.

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APPENDIXES

APPENDIX A

TABLES

TABLE I

DATES OF PLANTING, INFESTATION, REINFESTATION, AND HARVEST

Planting Dates

The 1979-80 study was planted on 15 October 1979 at the Perkins, OK, Research Station.

The 1980-81 study was planted on 2 October 1980 at Stillwater, OK.

Infestation Dates

Fall 1979	Spring 1980
Infested plots 20-24 Nov.	Infested plots 25-29 Feb.
Reinfested 15 plots 1 Dec.	Reinfested 10 plots 5-6 Mar. and 10 plots 25-26 Mar.
Fall 1980	**Spring 1981**
Infested plots 16-18 Oct.	Infested plots 17-20 Feb.
Reinfested 10 plots 31 Oct. and 20 plots 7 Nov.	Reinfested 20 plots 25-26 Feb. and 15 plots 11-12 Mar.

Harvest Dates

The 1979-80 study was harvested from 23-27 June 1980.

The 1980-81 study was harvested on 6 and 8-11 June 1981.

TABLE II

DAMAGE RATING SCHEME FOR GREENBUGS BASED ON A ONE TO NINE SCALE WITH FIVE PLANTS/(0.30 METER-ROW)

1. No greenbug damage is present. The plants are in near perfect condition with no tip burn.
2. Plants are very healthy, no necrosis is present.
3. Small necrosis spots begin to appear. No yellowing occurs on the leaves. All plants are alive and healthy.
4. More necrosis appears on plants than number three, and a small amount of yellowing appears on the lower leaves.
5. Plants are peppered with necrosis and yellowing of the lower and upper leaves becomes quite apparent.
6. Leaves have more yellowing than number five and some of the leaves begin to turn brown. Plants may have become stunted and one plant may have died.
7. Extensive yellowing and stunting of plants occurs and two or three of the plants may have died.
8. Extensive damage has occurred, almost all the leaves have turned brown. Generally only one or two of the plants are alive.
9. All plants in the 0.30 meter row (1 ft-row) are dead or dying.

TABLE III

NUMBER OF SEED/PLANT AND DAMAGE RATINGS[1] FOR RESISTANT (R) AND SUSCEPTIBLE (S) VARIETIES FOR FALL 1979 FIELD PLOTS AT THE PERKINS, OK, STATION[2]

Level	No. Seed/Plant		Damage Rating	
	R	S	R	S
00	98.28	111.44	1.60	1.40
10	81.12	77.88	3.20	2.80
20	69.84	25.28	3.40	5.80
40	57.44	30.16	5.40	6.60
60	35.88	8.08	6.80	8.20
Overall Means	68.51	50.57	4.08	4.96

[1]Damage ratings based on a one to nine scale.

[2]Average of five reps.

TABLE IV

YIELD DATA FOR THE RESISTANT AND SUSCEPTIBLE VARIETIES FROM FALL 1979 FIELD PLOTS AT THE PERKINS, OK, STATION[1]

Level	Resistant		Susceptible	
	Yield (kg/ha)	Reduction From Control	Yield (kg/ha)	Reduction From Control
00	1857.14 (27.61)[2]		2511.59 (37.34)	
10	1558.62 (23.18)	-298.52	1819.82 (27.06)	-691.77
20	1320.38 (19.63)	-536.76	651.58 (9.69)	-1860.01
40	1234.27 (18.35)	-622.87	703.24 (10.46)	-1808.35
60	686.02 (10.20)	-1171.12	200.93 (2.99)	-2310.66

[1]Average of five reps.

[2]Data in parenthesis is converted to bu/ac.

TABLE V

NUMBER OF SEED/PLANT AND DAMAGE RATINGS[1] FOR RESISTANT (R) AND SUSCEPTIBLE (S) VARIETIES FROM SPRING 1980 FIELD PLOTS AT THE PERKINS, OK, STATION[2]

	No. Seed/Plant		Damage Rating	
Level	R	S	R	S
00	102.20	91.30	1.70	1.70
20	102.88	82.88	2.30	2.70
40	86.94	46.22	3.30	4.30
60	46.18	22.58	4.90	6.60
80	42.94	6.68	6.00	7.90
Overall Mean	76.23	49.81	3.64	4.64

[1]Damage ratings based on a one to nine scale.

[2]Average of five reps.

TABLE VI

YIELD DATA FOR RESISTANT AND SUSCEPTIBLE VARIETIES FROM SPRING 1980 FIELD PLOTS AT THE PERKINS, OK, STATION[1]

	Resistant		Susceptible	
Level	Yield (kg/ha)	Reduction From Control	Yield (kg/ha)	Reduction From Control
00	1903.06 (28.30)[2]		1948.99 (28.98)	
20	1921.72 (28.57)	+18.66	1799.73 (26.76)	-149.26
40	1539.96 (22.90)	-363.10	1030.47 (15.32)	-918.52
60	855.37 (12.72)	-1047.69	369.11 (5.89)	-1552.88
80	720.47 (10.71)	-1182.59	130.60 (1.94)	-1818.39

[1]Average of five reps.

[2]Data in parenthesis is converted to bu/ac.

TABLE VII

NUMBER OF SEED/PLANT AND DAMAGE RATINGS[1] FOR RESISTANT (R) AND SUSCEPTIBLE (S) VARIETIES FROM FALL 1980 FIELD PLOTS AT STILLWATER, OK[2]

	No. Seed/Plant		Damage Rating	
Level	R	S	R	S
00	425.68	390.80	1.00	1.50
10	426.30	373.54	1.80	1.80
20	382.80	303.02	2.50	2.60
40	308.14	174.22	3.50	5.10
60	182.54	34.16	4.70	6.70
Overall Means	345.09	255.15	2.70	3.54

[1]Damage ratings based on a one to nine scale.

[2]Average of five reps.

TABLE VIII

YIELD DATA FOR RESISTANT AND SUSCEPTIBLE VARIETIES FROM FALL 1980 FIELD PLOTS AT STILLWATER, OK[1]

	Resistant		Susceptible	
Level	Yield (kg/ha)	Reduction From Control	Yield (kg/ha)	Reduction From Control
00	14630.76 (217.55)[2]		14075.25 (209.29)	
10	14362.42 (213.56)	-268.34	13584.98 (202.00)	-490.27
20	12486.75 (185.67)	-2144.01	10763.74 (160.05)	-3311.51
40	10046.16 (149.38)	-4584.60	7284.11 (108.31)	-6791.14
60	5846.92 (86.94)	-8783.54	1259.64 (18.73)	-12815.61

[1]Average of five reps.

[2]Data in parenthesis converted to bu/ac.

TABLE IX

NUMBER OF SEED/PLANT AND DAMAGE RATINGS[1] FOR THE RESISTANT (R) AND SUSCEPTIBLE (S) VARIETIES FOR SPRING 1981 FIELD PLOTS AT STILLWATER, OK[2]

	No. Seed/Plant		Damage Rating	
Level	R	S	R	S
00	402.94	416.68	1.10	1.60
20	410.94	401.16	1.60	2.40
40	355.32	234.70	2.20	4.60
60	244.06	110.48	3.80	6.10
80	132.20	17.56	4.90	7.20
Overall Means	282.65	236.12	2.72	4.38

[1]Damage rating based on a one to nine scale.

[2]Average of five reps.

TABLE X

YIELD DATA FOR THE RESISTANT AND SUSCEPTIBLE VARIETIES FROM SPRING 1981 FIELD PLOTS AT STILLWATER, OK[1]

	Resistant		Susceptible	
Level	Yield (kg/ha)	Reduction From Control	Yield (kg/ha)	Reduction From Control
00	13786.75 (205.00)[2]		14404.12 (214.18)	
20	13710.07 (203.86)	-76.66	14055.08 (208.99)	-349.04
40	12480.70 (185.58)	-1306.03	8816.78 (131.10)	-5587.34
60	8084.41 (120.21)	-5702.32	4114.50 (61.18)	-10289.62
80	4598.72 (68.38)	-9188.01	733.72 (10.91)	-13670.40

[1]Average of five reps.

[2]Data in parenthesis is converted to bu/ac.

TABLE XI

THE AVERAGE GROWTH[1], FINAL GREENBUG COUNT AND AVERAGE FOLIAGE WEIGHT (G) FOR THE RESISTANT (R) AND SUSCEPTIBLE (S) VARIETIES IN THE GREENHOUSE

	Growth (cm)		No. of Greenbugs		Foliage Wt. (g)	
Level	R	S	R	S	R	S
00	21.41	21.14			0.2863	0.2613
05	22.91	19.73	31.38	41.13	0.1913	0.2150
10	19.75	12.83	75.38	82.50	0.1763	0.1463
15	16.19	8.34	107.38	122.88	0.1113	0.1350
20	8.18	5.54	160.25	129.50[2]	0.0900	0.1088
Overall Means	17.69	13.51	74.87	75.20	0.1710	0.1733

[1]Growth = final plant height - initial plant height.

[2]Plants at this infestation level were dying.

TABLE XII

THE AVERAGE PERCENT REDUCTIONS IN FOLIAGE WEIGHT, ROOT WEIGHT, FOLIAGE LENGTH, AND ROOT VOLUME AT VARIOUS LEVELS OF GREENBUG INFESTATION IN THE GREENHOUSE

	Foliage Weight		Root Weight	
	Resistant	Susceptible	Resistant	Susceptible
	68.56%	58.36%	58.70%	78.70%
Ave (R&S) combined	63.46%		68.70%	
	Foliage Length		**Root Volume**	
	Resistant	Susceptible	Resistant	Susceptible
	61.79%	73.79%	53.96%	80.30%
Ave (R&S) combined	67.79%		67.13%	

TABLE XIII

GREENBUG EXPOSURE TIME[1] AT VARIOUS INFESTATION LEVELS FOR THE RESISTANT (R) AND SUSCEPTIBLE (S) VARIETIES

	Fall 1979		Spring 1980		Fall 1980		Spring 1981	
Level	R	S	R	S	R	S	R	S
10	9.9	9.8			11.5	12.4		
20	23.4	21.7	13.8	14.0	23.3	25.8	13.4	13.0
40	28.6	25.6	24.2	24.2	21.7	28.4	30.4	39.3
60	30.2	28.3	35.9	33.5	33.5	33.9	40.7	42.2
80			42.6	40.4			49.5	47.7
Overall Means	23.0	21.4	29.1	28.0	22.5	25.13	33.5	35.6

[1]Number of days required for the aphid population to increase to the designated level of the plot (average of five reps).

APPENDIX B

FIGURES

Figure 1. Grain Yield/Plant for the Resistant and Susceptible Varieties for Various Infestation Levels at the Perkins, OK, Station, Fall 1979.

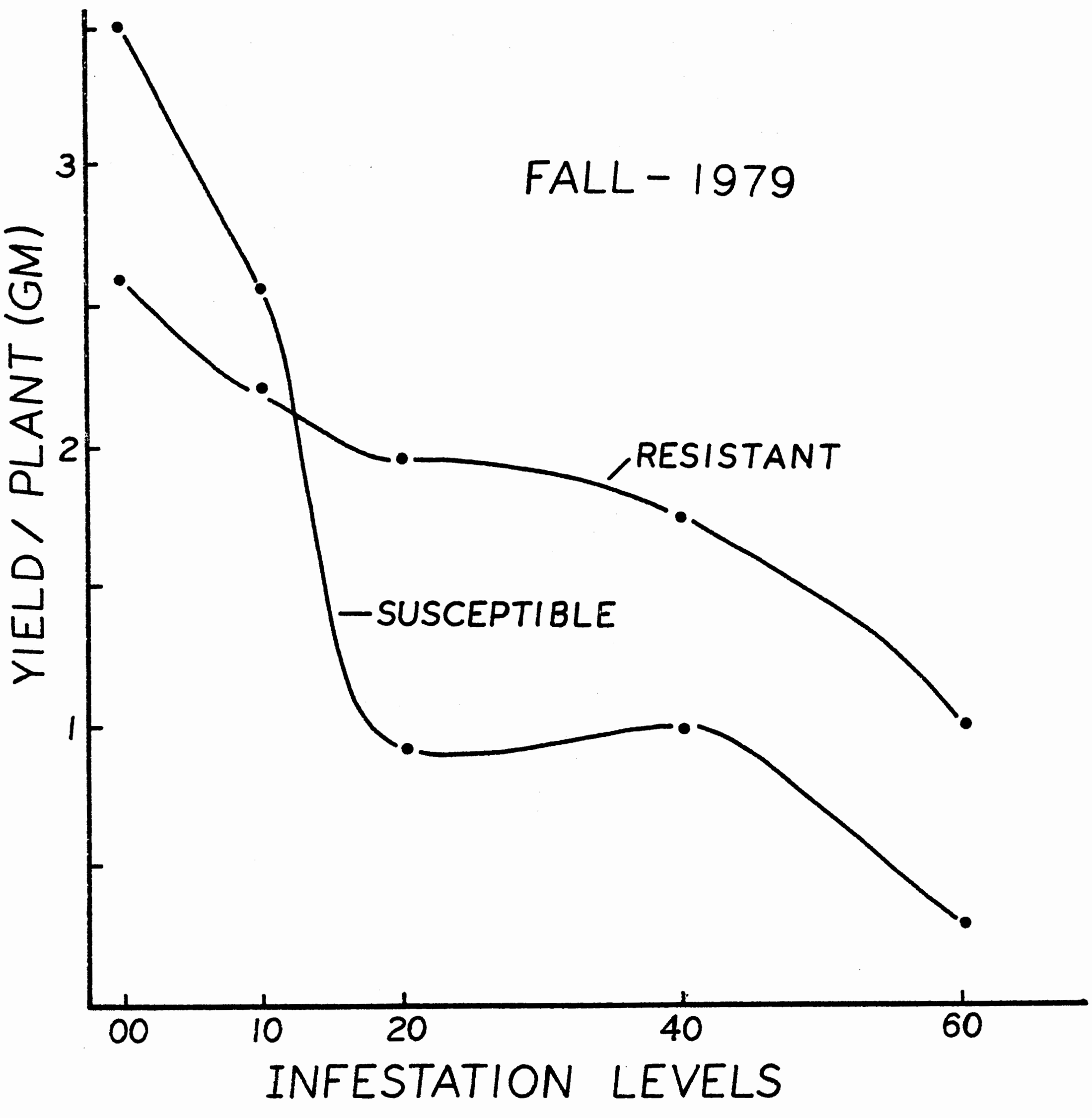
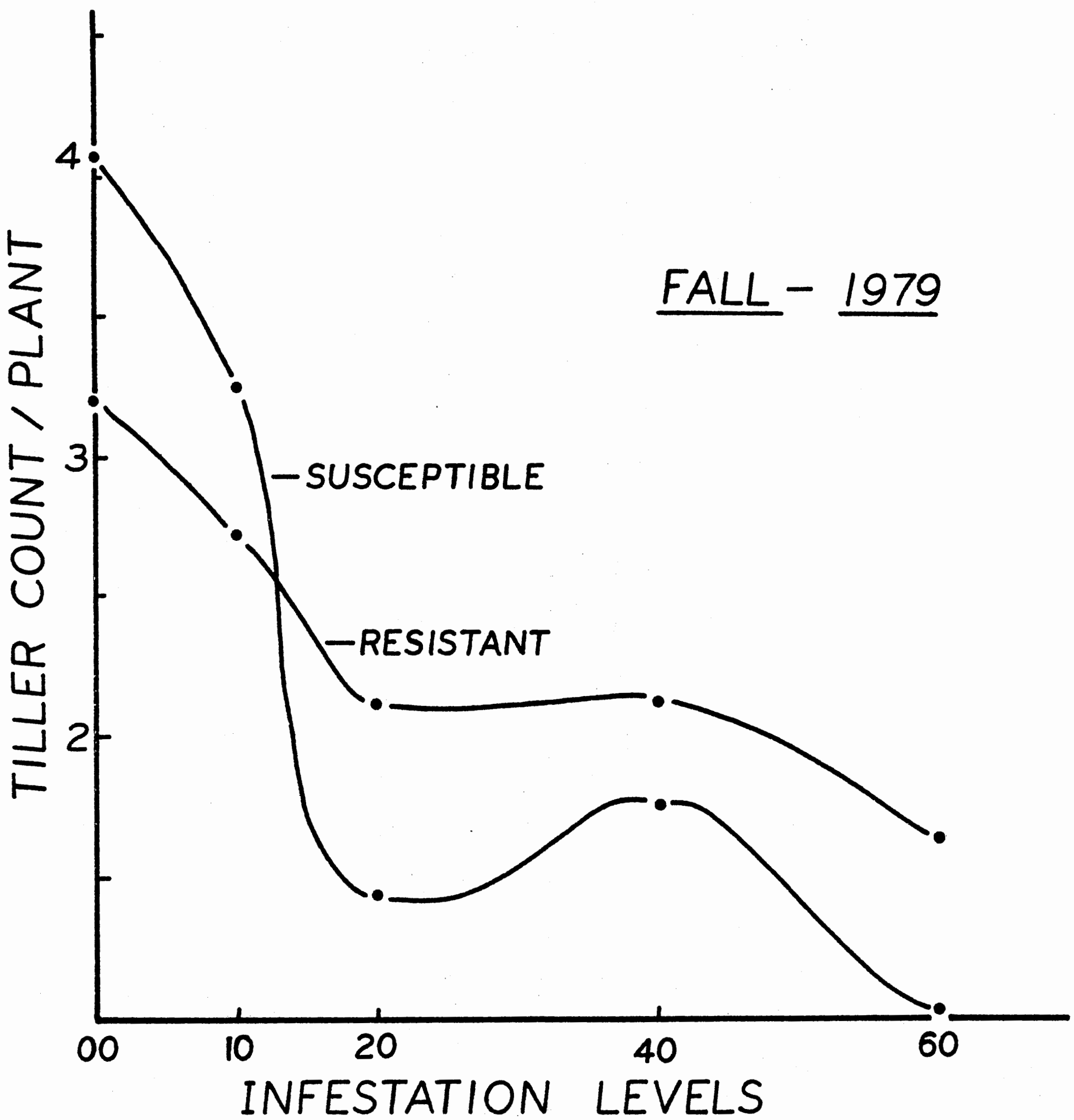

FALL - 1979
YIELD / PLANT (GM)
3
2
1
RESISTANT
SUSCEPTIBLE
00
10
20
40
60
INFESTATION LEVELS

Figure 2. The Number of Fertile Tillers for the Resistant and Susceptible Varieties for Various Infestation Levels at the Perkins, OK, Station, Fall 1979.



FALL - 1979
TILLER COUNT / PLANT
4
3
2
—SUSCEPTIBLE
—RESISTANT
00
10
20
40
60
INFESTATION LEVELS

Figure 3. Grain Yield/Plant for the Resistant and Susceptible Varieties for Various Infestation Levels at the Perkins, OK, Station, Spring 1980.

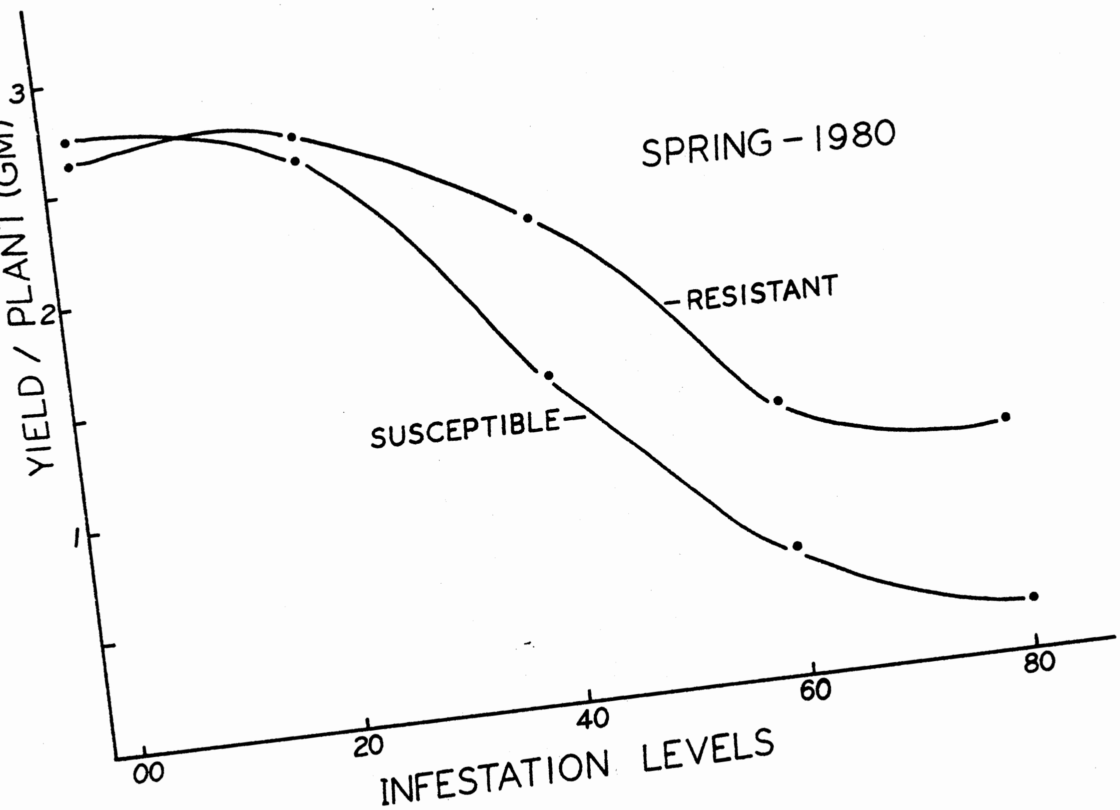

SPRING - 1980
YIELD / PLANT (GM)
3
2
1
RESISTANT
SUSCEPTIBLE
00
20
40
60
80
INFESTATION LEVELS

Figure 4. The Number of Fertile Tillers for the Resistant and Susceptible Varieties for Various Infestation Levels at the Perkins, OK, Station, Spring 1980.

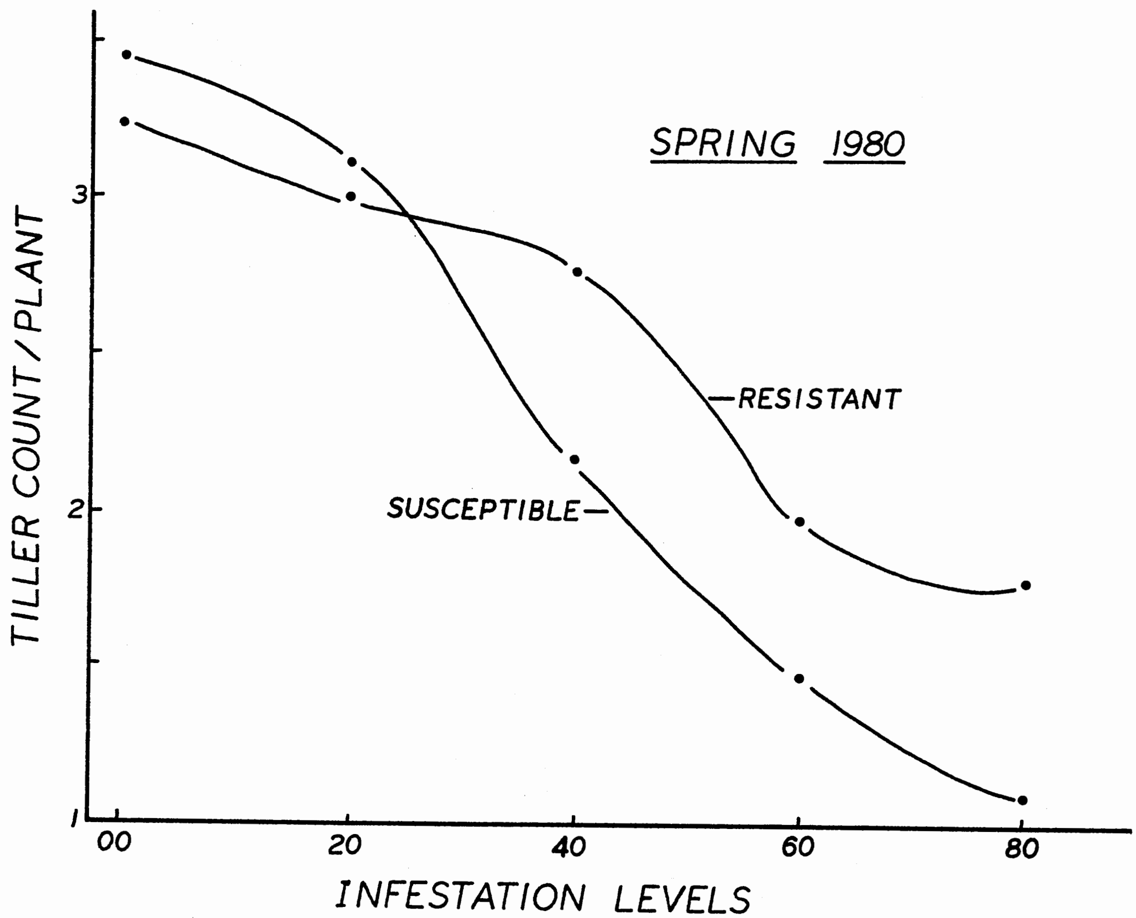
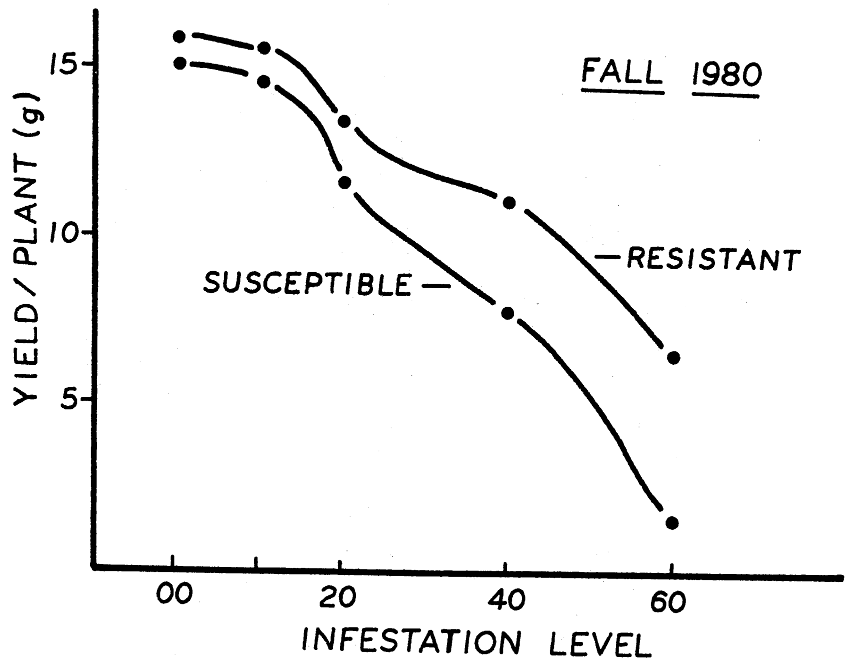

SPRING 1980
TILLER COUNT/PLANT
3
2
1
RESISTANT
SUSCEPTIBLE
00
20
40
60
80
INFESTATION LEVELS

Figure 5. Grain Yield/Plant for the Resistant and Susceptible Varieties for Various Infestation Levels at Stillwater, OK, Fall, 1980.

Figure 6. The Number of Fertile Tillers for the Resistant and Susceptible Varieties for Various Infestation Levels at Stillwater, OK, Fall 1980.


FALL 1980
YIELD / PLANT (g)
15
10
5
SUSCEPTIBLE
RESISTANT
00
20
40
60
INFESTATION LEVEL

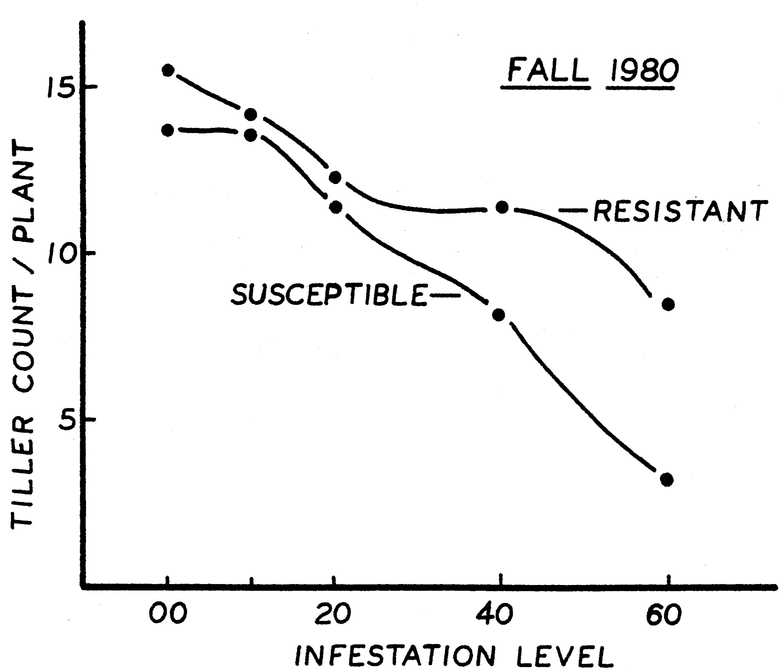
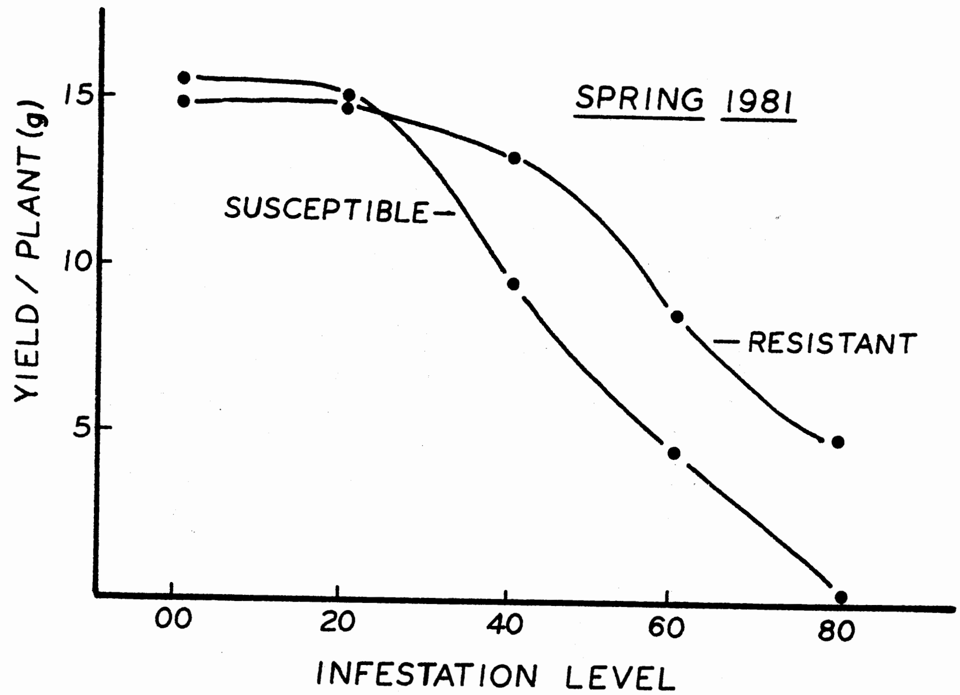

FALL 1980
TILLER COUNT / PLANT
15
10
5
RESISTANT
SUSCEPTIBLE
00
20
40
60
INFESTATION LEVEL

Figure 7. Grain Yield/Plant for the Resistant and Susceptible Varieties for Various Infestation Levels at Stillwater, OK, Spring, 1981.

Figure 8. The Number of Fertile Tillers for the Resistant and Susceptible Varieties for Various Infestation Levels at Stillwater, OK, Spring 1981.


SPRING 1981
YIELD / PLANT (g)
15
10
5
SUSCEPTIBLE
RESISTANT
00
20
40
60
80
INFESTATION LEVEL

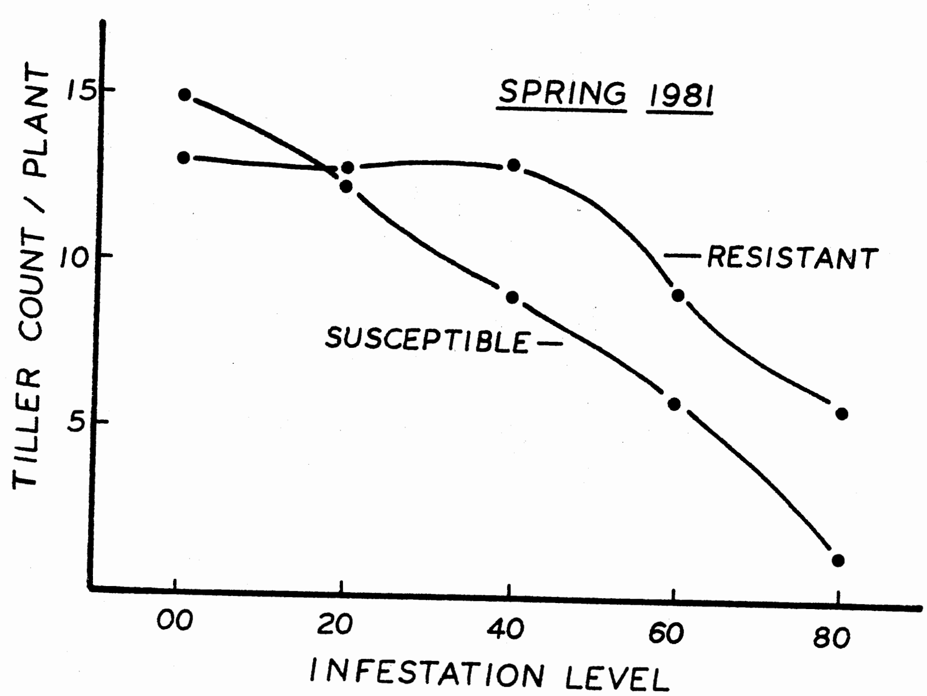
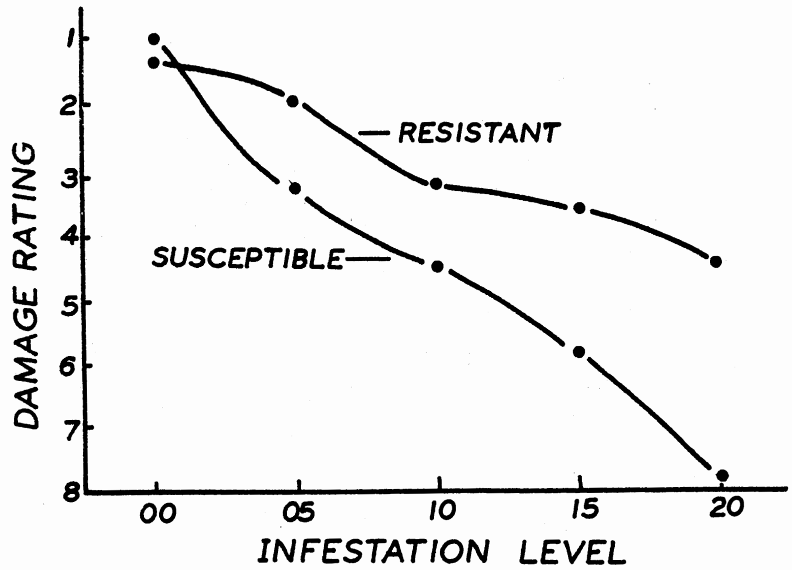

SPRING 1981
TILLER COUNT / PLANT
15
10
5
RESISTANT
SUSCEPTIBLE
00
20
40
60
80
INFESTATION LEVEL

Figure 9. Damage Rating for the Resistant and Susceptible Varieties at Various Infestation Levels in the Greenhouse.

Figure 10. Root Volume for the Resistant and Susceptible Varieties at Various Infestation Levels in the Greenhouse.


DAMAGE RATING
1
2
3
4
5
6
7
8
RESISTANT
SUSCEPTIBLE
00
05
10
15
20
INFESTATION LEVEL

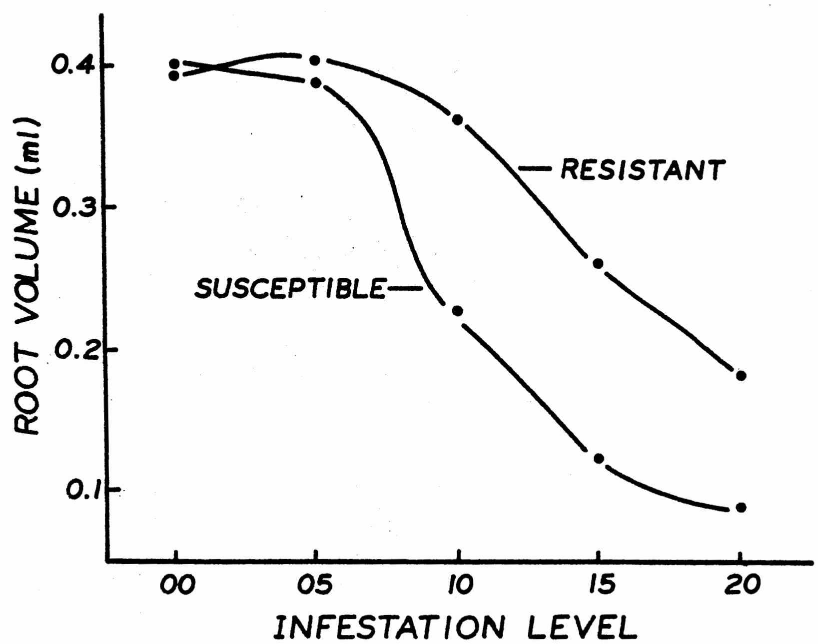
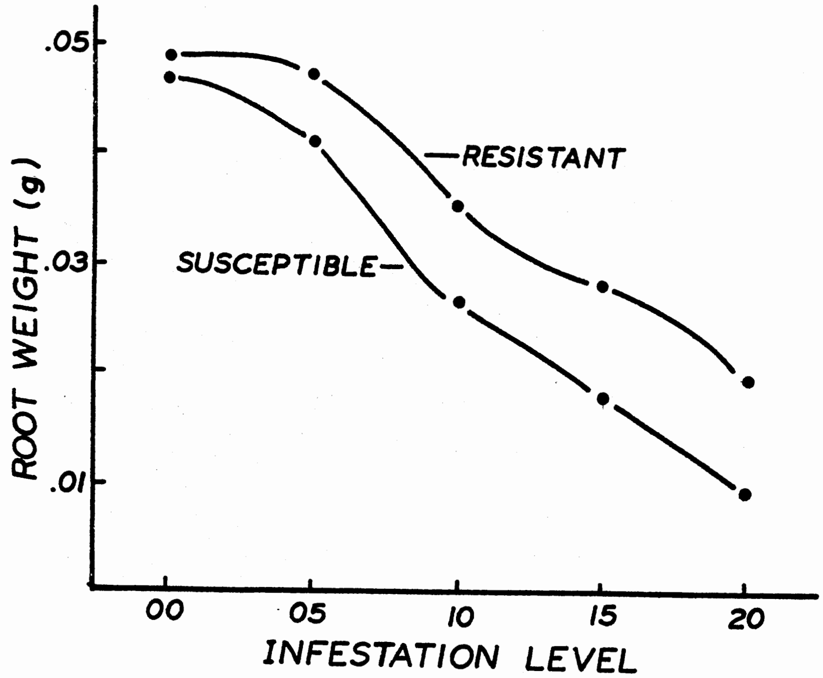
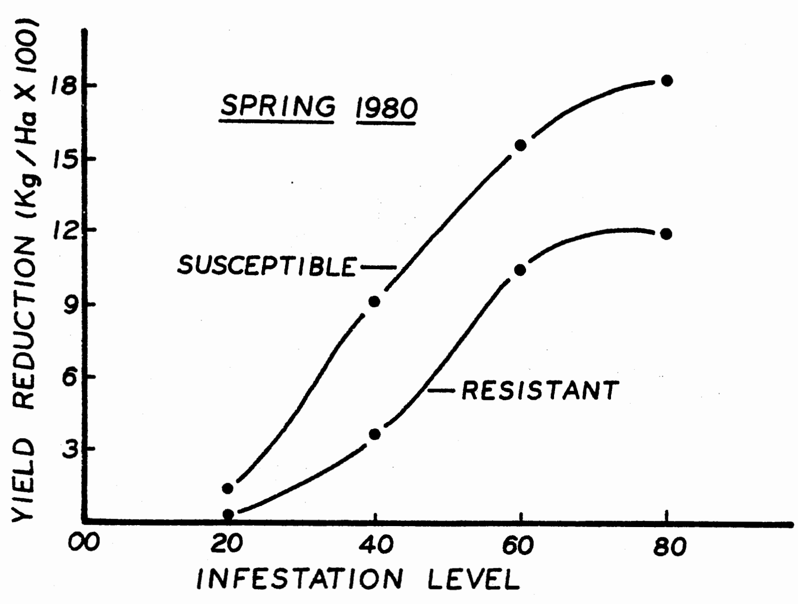

ROOT VOLUME (ml)
0.4
0.3
0.2
0.1
RESISTANT
SUSCEPTIBLE
00
05
10
15
20
INFESTATION LEVEL

Figure 11. Root Weight for the Resistant and Susceptible Varieties at Various Infestation Levels in the Greenhouse.

Figure 12. Yield Reduction for the Resistant and Susceptible Varieties for Various Infestation Levels at the Perkins, OK, Station, Spring, 1980.



ROOT WEIGHT (g)
.05
.03
.01
RESISTANT
SUSCEPTIBLE
00
05
10
15
20
INFESTATION LEVEL



YIELD REDUCTION (Kg / Ha X 100)
18
15
12
9
6
3
SPRING 1980
SUSCEPTIBLE
RESISTANT
00
20
40
60
80
INFESTATION LEVEL

Figure 13. Yield Reduction for the Resistant and Susceptible Varieties for Various Infestation Levels at Stillwater, OK, Spring 1981.

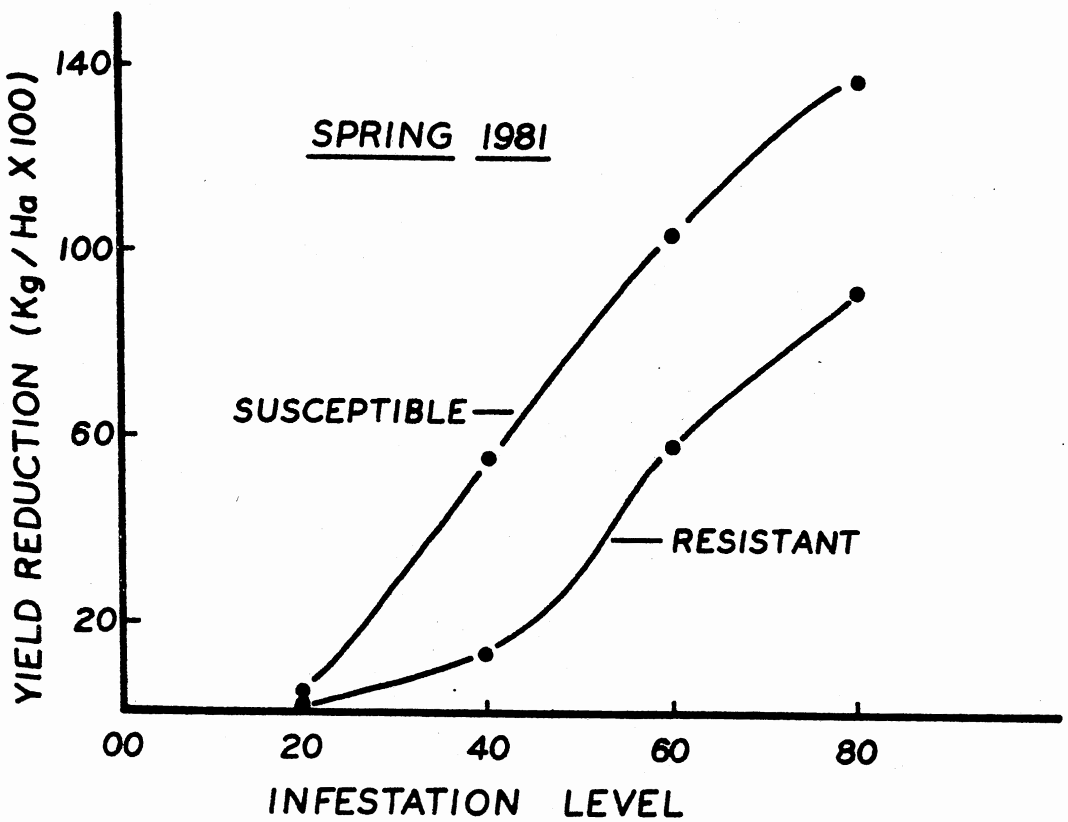
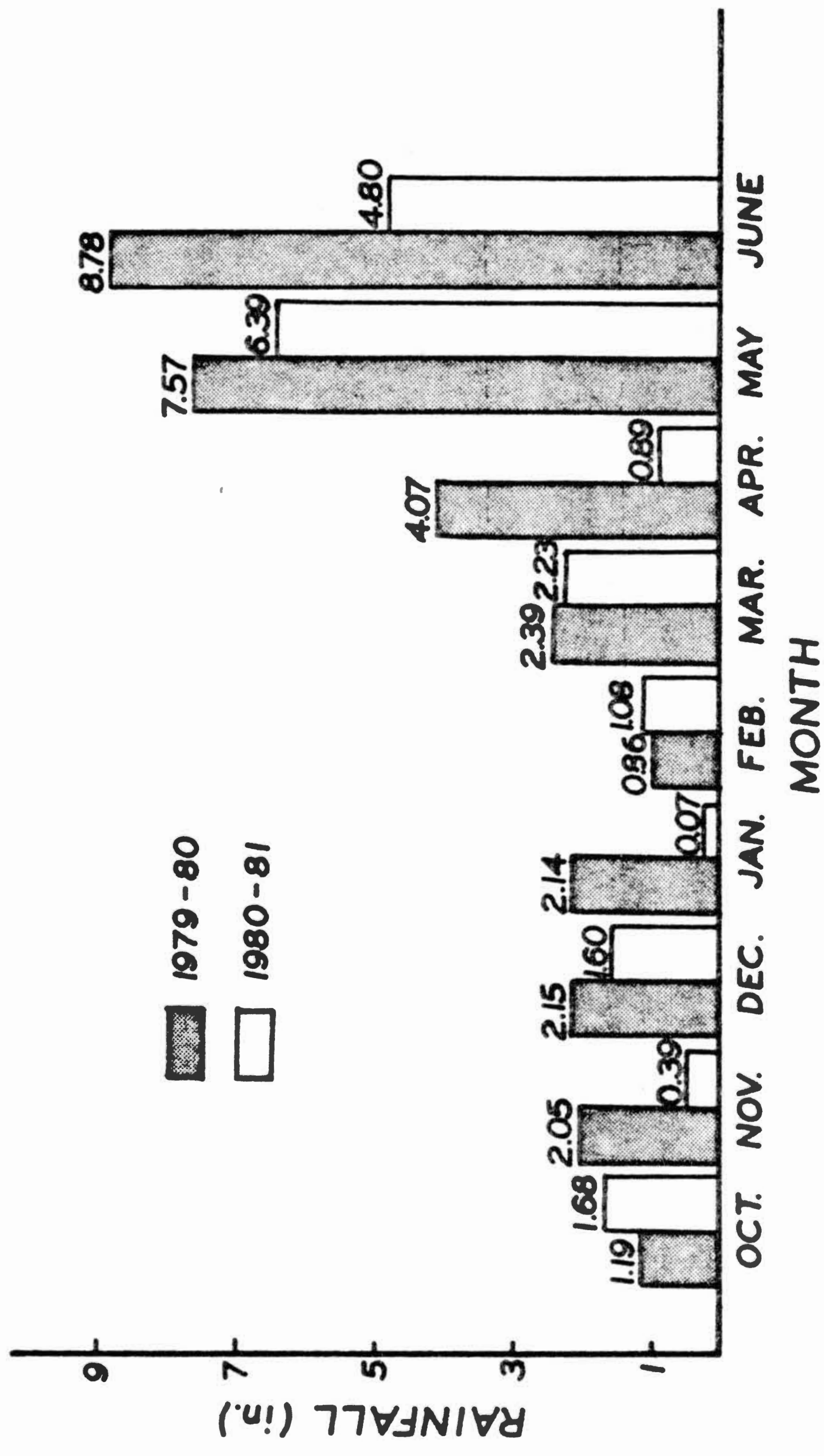

SPRING 1981
YIELD REDUCTION (Kg / Ha X 100)
140
100
60
20
SUSCEPTIBLE
RESISTANT
00
20
40
60
80
INFESTATION LEVEL

Figure 14. The Total Monthly Rainfall Received at the Perkins, OK, Station, and the Stillwater, OK, Stations, 1979-1981.



RAINFALL (in.)
1
3
5
7
9
1979-80
1980-81
1.19
1.68
2.05
0.39
2.15
1.60
2.14
0.07
0.96
1.08
2.39
2.23
4.07
0.89
7.57
6.30
8.78
4.80
OCT.
NOV.
DEC.
JAN.
FEB.
MAR.
APR.
MAY
JUNE
MONTH

VITA

Duane Dean Simon

Candidate for the Degree of

Master of Science

Thesis: REDUCTION OF YIELD COMPONENTS AND GREENBUG ECONOMIC THRESHOLDS IN A RESISTANT AND A SUSCEPTIBLE VARIETY OF WHEAT

Major Field: Entomology

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